Method and stabilization system of position-sensitive spectrometer based on semiconductor strip detector

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Abstract. The paper proposes a method and its realization for stabilizing the characteristics of a multichannel position-sensitive spectrometer. The device uses a new design of the semiconductor strip detector, which allows a simultaneous injection of stable in time electric charges on all strips. This solution enables the electronics to track changes in the conversion characteristics of all electronic channels including detectors strips, and correct them during the spectrometer operation. In addition, the proposed detector design makes it possible to control the signal propagation along the strips, thus providing an on-line check of the integrity of strips metallization and the quality of their connection with the readout electronics.

1. Introduction

Position-sensitive systems are widely used in nuclear physics, astrophysics, high-energy physics, and mass-spectrometry to record the trajectories and energies of charged particles [1], [2], [3]. The developments in this field are being carried out systematically at the Ioffe Institute. Position-sensitive systems described in [4], [5] utilize semiconductor strip detectors. During long-term influence of radiation, unstable temperature and other factors including the mechanical stress, the changes of the detectors characteristics and spectrometric channels can arise.

Stabilization of the spectrometer conversion characteristics is usually carried out by applying reference signals to the preamplifier input, or analyzing the reference peaks in the measured energy spectrum. In the first method, the system does not follow the changes in the performance of the detector itself (e.g., violation in strips metallization and changes in the properties of the metal-strip interface). In the second case, it is impossible sometimes to select two reference peaks at the beginning and the end of the detector signal amplitude distribution for stabilizing the offset and the slope of the conversion characteristic of individual channel. In addition, in a position-sensitive spectrometer, the same reference peaks cannot be detected from all strips, like it happens in the case of mixed irradiation with different particles.

This paper proposes the method and the system for stabilizing the conversion characteristics of individual channels and their combination in a multichannel position-sensitive spectrometer.
2. Method and stabilization system

The position-sensitive spectrometer (Fig. 1) contains a strip detector, a set of spectrometric channels, a calibration pulse generator, and a system of the strips signal readout control and data acquisition. The individual spectrometric channel includes a strip of the detector, charge-sensitive preamplifier, a shaping amplifier (these two represent a signal readout part), a gain controlled amplifier (scaling amplifier), an analog-to-digital converter (ADC) and a digital-to-analog converter (DAC). The control of the channel characteristics and data acquisition are carried out by a system that includes a field-programmable gate array (FPGA), a microcontroller (MC) and data memory (RAM). The computer (PC) is connected to the spectrometer via Ethernet.

![Figure 1. Block diagram of a multichannel position-sensitive spectrometer with a stabilization system.](image)

The design of the advanced strip detector is presented in Fig. 2. It includes a sensitive volume based on high-resistivity semiconductor (1) enclosed between the front and back contacts (2). The contacts represent isolated strip electrodes (4) with metallization (5). The strips are separated by a dielectric (3). A specific feature of the proposed detector is an insulated metal electrode (test electrode) (7) on each strip located on the side opposite to the contact connected with electronics. As a result, local capacities (6) arise between the metalized elements (5) and the strips (7), which allows to inject the charge to all strips simultaneously.

Operation of the stabilization system consists in the following. The control system triggers periodically the generator of calibration signals of different amplitudes, which are sent to the test electrode. The signal amplitudes correspond to the lower and upper limits of the ADC conversion range. The signals from strips are read-out by charge-sensitive preamplifiers and then treated by the shaper and fed to the scaling amplifier. Finally, they are digitized by the ADC and transferred to the data acquisition system (DAQ). Thus, the calibration signals passing through the entire spectrometric channel including the detectors strip provide information on operation of all components of the spectrometer.

The DAC control voltages correcting the gain and the offset in the individual signal readout channel are generated by the DAQ. For that, the amplitudes of the reference signals and the baseline measured by ADC are compared with the previously stored reference values of the calibration pulses amplitudes. As a result of comparison, the DAC control voltages from the DAQ affect the bias and the gain inputs of the scaling amplifiers so that to revert the conversion characteristic to the initial level, i.e. to stabilize the full conversion gain and the baseline potential.
Figure 2. Strip detector processed as silicon P+I-N+ structure with P+ strips.

It should be noted that the proposed system and the algorithm of its operation allow also the use of a larger number of reference pulses, which makes it possible to stabilize the characteristics of nonlinear converters. Usually, it is not necessary to correct the conversion characteristics permanently (i.e., in each detected event). It is reasonable, however, to trace the dynamics of the characteristics periodically in some calibration windows and perform the conversion characteristics correction provided that the statistical majority of the reference pulses are beyond the windows.

Such a stabilization algorithm is implemented using a microcontroller. In this case digital windows are installed on the shoulders of the obtained amplitude distribution of the reference signal close to the Gaussian. While operating, the average numbers of events registered within a certain time interval in each window are compared, and the correction signal is generated basing on the results of comparison.

The proposed method and its implementation assume the analog electronic stabilization of the conversion characteristics, when the formation of numerous amplitude distributions of a multichannel position-sensitive spectrometer is carried out directly in the DAQ memory. At the same time, data transfer to a computer via a serial channel is carried out periodically. Therefore, this method can be also realized at the PC software, when the set of signals, including the reference ones, is treated together. It should be emphasized that the use of calibration signals reduces the requirements for the long-term stability of all elements of the signal readout/processing electronics and ensures the stability of the spectrometer operation via the stability of the test signal generator. Besides, integration of the test contact into the detector structure is critical, and the use of thin-film technologies for processing this element is preferable.

Realization of the described algorithm is focused on the experiments in which strip detectors with several tens of wide strips (several mm width) are used. In this case, the position-sensitive spectrometer can be realized basing on single channel front-end chips model A225, fast scaling amplifier AD835 and 4-channel 12-bit A/D converters LTC2174-12, designed for digitizing high frequency, wide dynamic range signals. Application of A/D converters LTC2174-12 with serial data transmission over differential pair allows FPGA type EP3C16Q240 to record signals simultaneously for 120 ns up to 64 strips. Algorithms for analyzing the digitized signals are developed on FPGA and a microcontroller, which allow minimizing the time adjustment the characteristics within a few microseconds.
3. Conclusion

The proposed method for stabilization of position-sensitive spectrometer operation is applicable for the spectrometers built on the most advanced type of particle sensors, semiconductor detectors processed by planar technology. The approach enables to minimize the changes of conversion characteristics arising from variations in temperature and other causes. Owing to the proposed design of the strip detector, it is possible to check the integrity of strips metallization and the quality and reliability of microwire bonding of strips with readout electronics, and track the detector degradation under in situ irradiation.

References
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