SEGMENT POSITION DETERMINATION FOR THE MSU GERMANIUM DETECTORS

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1. Introduction

An array of eighteen thirty-two-fold segmented germanium detectors (MSU detectors) has been developed at the National Superconducting Cyclotron Laboratory for use in intermediate-energy experiments with exotic beams 1. High-purity germanium detectors such as the MSU detectors will provide better energy resolution in gamma-ray detection experiments with fast exotic beams than scintillation detectors such as the NaI(T1) array 2. To take advantage of the good intrinsic energy resolution of the germanium detectors, however, the position of the first gamma-ray interaction within the germanium crystal must be determined. Gamma-rays produced in experiments with intermediate energy beams, defined as a beam velocity of 0.2 to 0.5 times the speed of light, are considerably Doppler-shifted. The energy of the emitted photon in the moving frame of the exotic beam particle may be reconstructed from the energy of the photon observed in the laboratory, if the emission angle with respect to the beam axis is known. The segmentation of the outer contacts of the MSU detectors, shown in Fig. 1, will allow for a precise calculation of the angle of emission of the gamma ray, by allowing determination of the interaction point of the gamma ray within the germanium crystal. Calculation of the angle of gamma-ray emission requires the position of gamma

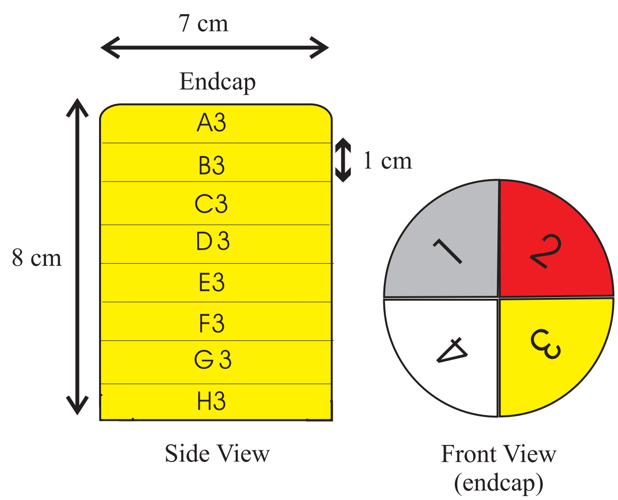

Figure 1: Electronic segmentation of the germanium crystal.

ray interaction in the germanium crystal with respect to the target position and beam axis to be known. This position determination requires two measurements: the position of each detector with respect to the target and beam axis, and the position of the thirty-two segments within each detector. The position of each detector is measured for each experimental configuration. The position of each segment within the germanium crystal must be measured when the crystal is contained within the cryostat of the detector, and kept at liquid nitrogen temperatures. Thus the segment positions will be measured as they would appear in an experiment. Two factors contribute to the loss of segment position resolution: the detectors

Figure 2: Segmented germanium detector mounted in the test stand.

are shipped with the crystal under vacuum, preventing a direct measurement of segment position; and the crystal is attached to a cooling rod, which can contract and expand a few millimeters with changes in detector temperature.

We have developed and implemented a system for determining segment positions in a cooled MSU thirty-two fold segmented germanium detector.

2. Mechanical Setup and Data Acquisition

The test stand used to automatically determine the segment positions is shown in Fig. 2. The detector is positioned such that the cylindrical cryostat containing the germanium crystal is centered within a movable ring. Centering of the cryostat is accomplished through the apparatus' four adjustable legs. A ^{57}Co source, 3 mm in diameter, is mounted in a copper block affixed to the movable ring. The copper block is one inch thick and 3.5 square inches in area, with a one millimeter hole in the center. The source is placed over the one millimeter hole, allowing the copper block to act as a collimator for the 122 keV gamma-rays emitted from the decay of ^{57}Co. A low-energy gamma-ray source was chosen for two reasons: the gamma rays are attenuated by 99% in one inch of copper; and Compton scattering is eliminated within the germanium, thus only full-energy peaks in the germanium crystal are detected. The ring on which the copper block is mounted allows the source of gamma rays to move 360 degrees around the cryostat, and up to sixteen inches linearly. This allows the source to move to any position around the surface of the cryostat, excluding the front and back faces of the cylinder. The motion of the source is driven by two synchronous stepping motors (Slo-Syn M063-LE09), one each for the linear and circular axes of motion. To better control the position of the source, an incremental optical encoder (BEI L25) is connected to each axis. The direction and magnitude of motion is controlled by LabVIEW programming and ValueMotion software, through a National Instruments PCStep four-axis closed-loop stepper board.

As a result of the automated position determination, a linear and angular position is specified for each of the thirty-two segments. These positions correspond to the linear and angular center of each segment. The center is defined as the position at which the number of 122 keV gamma-rays detected by the segment is greatest. Linear positions are measured with respect to the front face of the cryostat, the position of which is determined by a convergent laser sensor (PicoDot PD45VP6C100). Angular positions are measured with respect to the initial position of the source, which is determined by activation of a mechanical switch.

The source is moved to 100 positions along the length of the cryostat, and to 100 angular positions at each linear position. The number of positions was chosen to place the source of gamma rays directly over each segment for at least ten positions linearly, and twenty-five positions along the cryostat circumference. At each position, data for 20,000 gamma-ray events in the germanium crystal passes through a series of electronics prior to digitization by two 16-channel 12-bit ADCs (National Instruments PC-MIO-16E-4). The mechanical motion of the source and data acquisition are controlled by one LabVIEW program. The trigger for data acquisition is provided by the central contact of the germanium detector, which provides a signal when any of the thirty-two segments register a gamma-ray interaction. The central contact signal is fed first into a timing filter amplifier (Ortec 454) and then to a constant fraction discriminator (Tennelec 455). The output of the discriminator is delayed before it is passed to the ADCs as the event trigger. The energy signals from the thirty-two segments are fed first to shaping amplifiers (quad shapers manufactured at MSU), and then to an ASCOM NIM stretcher before digitization. Each of the 20,000 gamma-ray events takes approximately five microseconds to be processed through the electronics and LabVIEW, for a total scanning time of ten days for 10,000 positions. A 399 KB data file is generated for each of the 10,000 positions.

3. Data Analysis

To determine the linear and angular center position of each segment, the collected data is analyzed using a combination of Tcl and C programming. For each of the 10,000 positions of the ^{57}Co source, an energy spectrum is generated for each segment (Fig. 3). The center of the 122 keV photopeak is determined for each position, and the number of counts in a range of channels around the center is recorded. For each

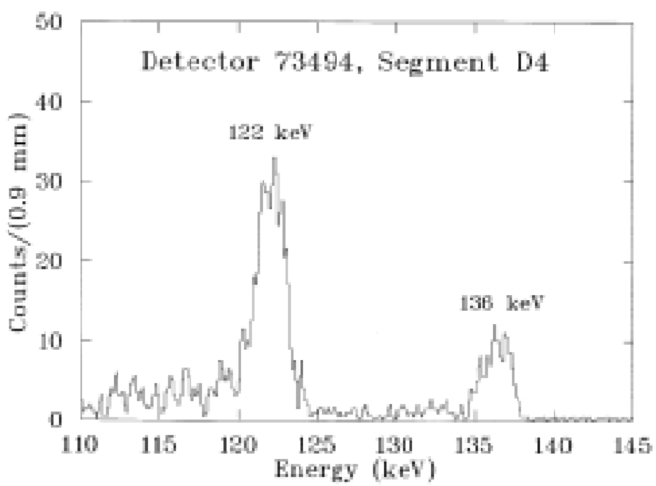

Figure 3: Typical energy spectrum for one detector segment. The 122 keV and 136 keV lines from the decay of ^{57}Co are visible. Here the ^{57}Co source is positioned close to the center of segment D4.

segment, at each fixed linear position, a graph of total counts under the photopeak versus angular position

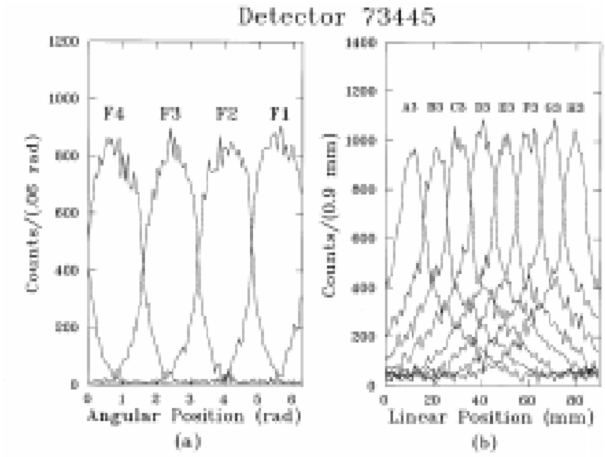

Figure 4: Curves of counts under the 122 keV photopeak versus position for detector number 73445. The centroid of each curve, determined using a weighted average method, specifies the center position of the corresponding segment.

is created. An example for the F segments is shown in Figure 4a. From this graph, the angular center position is determined, defined as the centroid of the curve for each segment. A weighted average method is used to calculate the centroid of each curve. This process is repeated for each of the one hundred linear positions. Multiple curves for each segment will result in multiple centroids for one segment. The centroids are averaged to produce the final angular center position for each segment. The procedure is then repeated for each of the one hundred angular positions, resulting in linear and angular center positions for each of the thirty-two segments.

4. Results and Performance

Six of eighteen MSU segmented germanium detectors have been successfully scanned and analyzed. The automation of the data acquisition process has allowed the positions of each segment to be determined with better accuracy than the two millimeters specified by the manufacturer. The errors in the linear segment positions determined using this method were 0.28 mm for the A segments, 0.23 mm for the B through G segments, and 0.43 mm for the H segments. The reason for the larger errors for the A and H center positions is illustrated in Figure 4b. The ^{57}Co source begins at the front face of the cryostat, at the edge of the A segments. Thus one tail of the curve for the A segments is largely missing. A similar discrepancy is obvious in the H segments. In this case, the copper block containing the ^{57}Co source cannot travel past the edge of the H segments due to the presence of the detector's cooling arm. For the angular segment positions, the errors for all segments are 1.06 milliradians.

In addition to the more accurate determination of the segment positions, other important characteristics of the crystal position and outer contact segmentation were observed as a result of these measurements. From Fig. 5, it can be seen that the germanium crystals are centered within the detector cryostats, not tilted in any direction. Secondly, the segments in each detector are equally spaced with respect to one another, both in linear and angular positions. Lastly, all detectors scanned show very similar linear and angular positions. Thus the manufacturer has been consistent with the placement of the germanium crystal and position of segments in the first six detectors.

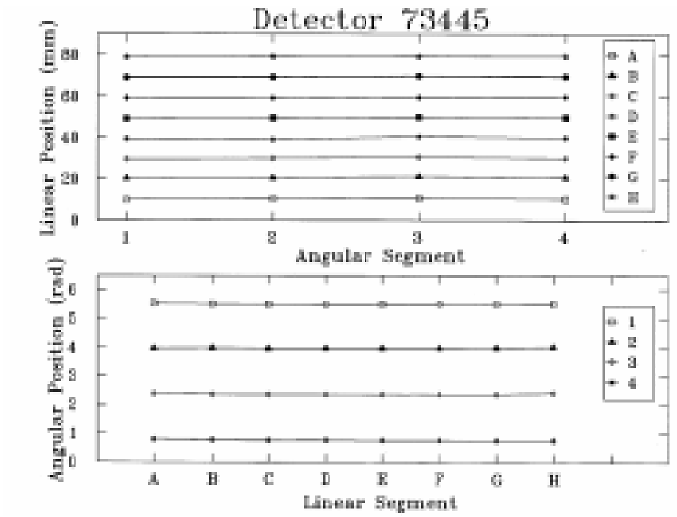

Figure 5: Linear and angular center positions for the thirty-two segments of detector number 73445. Error bars for both linear and angular positions are smaller than the plotting symbol.

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