A simple optical system for real-time size measurements of nuclear fuel pellets

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Advanced nuclear reactor designs use fuel forms that are built up from tens of thousands of tiny nuclear fuel pellets. These pellets, called TRISO particles, employ a dense layer of silicon carbide to trap radioactive fission products. The coated TRISO fuel acts as a containment system to prevent the release of fission products to the environment during accidents. Furthermore, these advanced nuclear reactor designs are regarded as an important part of the future hydrogen economy because they can be used to produce hydrogen more efficiently than electrolysis[1]. Rapid counting and measurement of TRISO spheres is a necessary technology for the development of these materials. A survey of commercial equipment found available devices lacking in speed, resolution and accuracy. We therefore elected to develop this capability in-house.

Based on the methods used by Wallisch and Koss[2] we employed a light obstruction concept where a slit of light (either an aperture or a focused beam) is blocked by a particle. The system projects light through a target transport cell and collects the light onto a photo receiver (see Figure 1 SYSTEM). The signal from the photo receiver is digitized by a high-speed analog-to-digital conversion unit. The signal is shown in Figure 2 (EVENT). When no light is blocked, the signal is high, but it then shrinks as the sphere passes through the slit and reaches a minimum when the sphere blocks the maximum amount of light. The maximum light blockage is proportional to the diameter of the sphere.

The error in our measurement can be limited by ADC resolution since we are trying to estimate the radius with the intensity of the obstruction. We attempt to better estimate the peak location by fitting the data to a parabola. In our software this is accomplished by finding the sampled peak, then locating 80 values on either side of the peak. These 161 values are used to find the coefficients of a least-squares error fit to a parabola and estimate the "true" minimum value of the curve. This improves the accuracy of the ADC resolution by a factor of 100.

Another problem was linked to the size of the particle handling system, which was designed for 1000 micron spheres. When smaller spheres (800 micron) pass through the cell, some overlapping can occur, causing a signal which deviates significantly from the ideal event (Figure 3). We detect these events in real-time by determining the error between a 3-point parabolic fit and the event. Large errors indicate possible multiple events. This provides an easy-to-compute method for finding multi-particle events that can be manually screened with software tools.

Experiments have estimated the counting accuracy as less than 0.075% error with a 95% confidence. The size measurement accuracy was on the order of 11 microns standard deviation for spheres 1000 microns in diameter. Although the current particle transport system does not support the maximum detection rate, electronically generated data showed rates of 200 particles per second, implying a throughput of 720,000 particles per hour. These rates and accuracies will improve the research and development cycle for the manufacturing of these pellets – which ultimate leads to safer, more efficient nuclear reactors producing energy for the benefit of us all.

REFERENCES

1. ORNL Review Vol. 35, No. 2, 2002

2. K. Wallisch and P. Koss, “Automatic size analysis of coated fuel particles,” Nucl. Tech. 35 (1977) 279-283