New Design Concepts for Magnetic TOF Detectors Lead to an Order of Magnitude Increase in Both Linearity and Operational Life

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Overview

- Refinements and new design concepts applied to the ETP/SGE magnetic TOF detector have lead to a 10X improvement in both its pulse dynamic range and its operational life.
- An orthogonal TOF system was utilized to verify the performance improvements of the new detector under realistic operating conditions.
- Major performance improvements are revealed by experimental results in the areas of pulse dynamic range, sustained current dynamic range, and operational life.

Introduction

- This group presented a new type of TOF detector utilizing combined magnetic/electrostatic electron deflection at the ASMS 2006 Conference.
- Since then, continual refinements along with new design concepts have lead to a 10X improvement in both the detector's pulse linearity (pulse dynamic range) and its operational life.
- Virtually all parameters influencing the detector's performance were addressed and optimized. These included electron optics design, magnetic circuit design, magnetic circuit materials and dynode surface materials and their processing.
- Performance improvements were achieved in each of these areas. The largest contribution resulted from manipulating the optics to achieve a major increase in the effective dynode area.
- A consequence of increasing the dynode area is a proportional decrease in electron impact density on the dynode leading to a proportionally increased operational life for the detector.
- Another consequence is a proportional increase in the internal capacitance that is available to the electron beam within the detector, leading to a proportionally increased pulse dynamic range and an improvement in dynamic range for sustained currents.
- Critical to understanding the influence of the various design parameters (and guiding the direction of the development) are the methods for evaluating the various performance parameters. These methods are detailed below.

General Methods

- For most measurements the detector was mounted in a modified, orthogonal TOF system utilizing an electron impact ion source which was operated to generate a TOF spectrum by continuously sampling the head space vapor above a sample of 1,3,5-Triazine, 2,4,6-tris(trifluoromethyl) (TRIS) (see Figure 1). A National Instruments PCI-5153EX Digitizer/Averager enabled the rapid accumulation and averaging of spectral data which was necessary for accumulating data with usable signal to noise in a practical time scale.

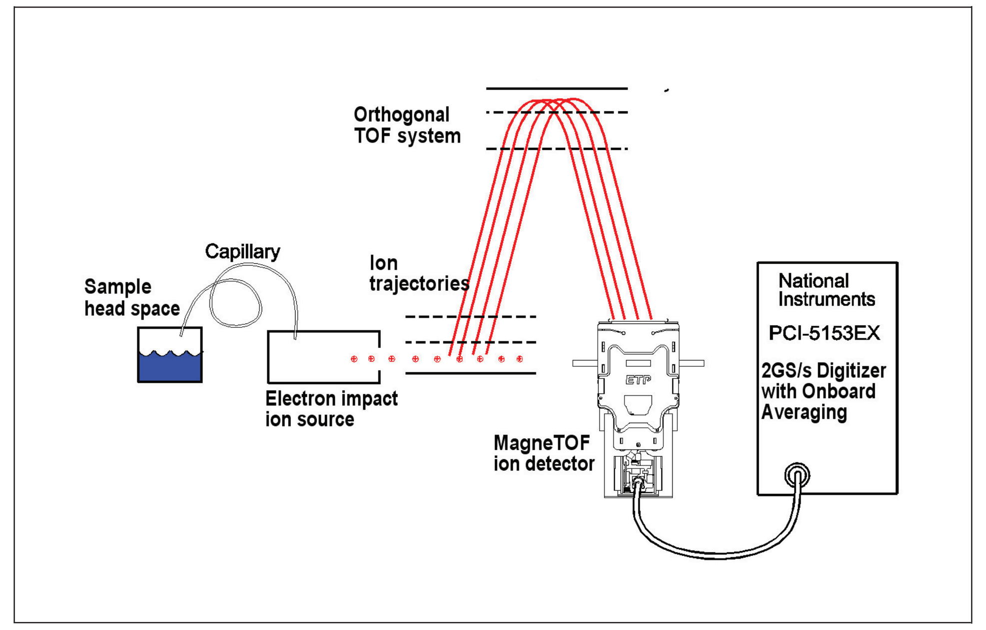

Figure 1. Experimental setup for pulse linearity and accelerated aging measurements.

- The relatively simple spectrum of TRIS enabled uncomplicated analysis of data: e.g. calculating total ion current based on the pulse height of the largest spectral peak was straightforward.

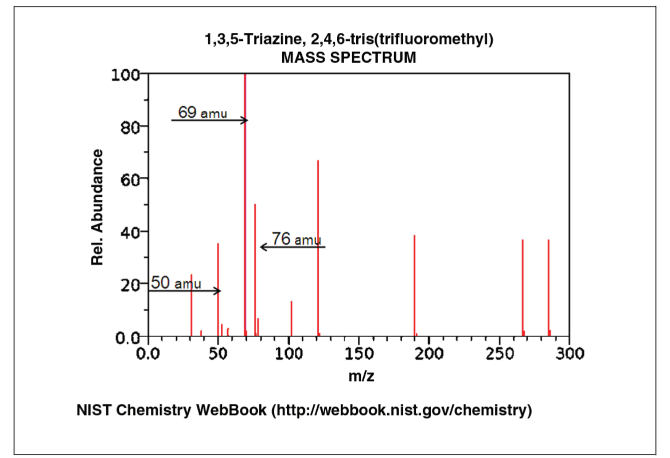

Figure 2. EI mass spectrum of 1,3,5-Triazine, 2,4,6-tris(trifluoromethyl) (TRIS) utilized for pulse linearity and aging studies. The mass peaks utilized and referred to in the pulse dynamic range study are identified.

Test Results Reveal a Major Advance in TOF Detector Technology

Pulse Dynamic Range

Dynamic range or pulse dynamic range is the common term used to describe a detector's linearity. This refers to the ratio of largest linear pulse to smallest measurable pulse in a single shot spectrum. Because the level of the smallest measurable pulse is determined by the details of a specific TOF system, the most meaningful measurement for a detector will be the level of the maximum linear pulse delivered by the detector. For convenience this is generally expressed as millivolts (mV) or volts (V) into a 50 Ω load (the usual preamp or digitizer impedance).

The measured abundances of several mass peaks were expressed as a ratio to the abundance of a relatively low abundance mass peak which occurred "early" in the spectrum (at 50 amu). An "early" mass peak was utilized to avoid distortions which could result from a preceding high abundance peak. Measuring the abundance ratio of the highest level peak (69 amu) to the "early" peak (50 amu) while increasing the ion flux provided a convenient method of measuring the detector's maximum linear pulse capability. As the signal level of the 69 amu peak is increased it will eventually distort. Because the 50 amu peak has ~8X lower intensity, it will remain unaffected and provides a reliable monitor of the ion input flux. Thus the change in the ratio of these abundances is an accurate measure of the linear limit for high level pulses.

As the ion source intensity was increased, the abundance ratio of the high level peak (69 amu) to the "monitoring" peak (50 amu) consistently remained at 8.0:1 until the electrical pulse corresponding to the 69 amu peak reached a level of ~2.5 volts (into 50 ohms). The ratio then slowly decreased to 90% of this level when the 69 amu peak reached ~4 volts. (Figure 3). This is a 10 times increase in linearity over earlier version magnetic detectors.

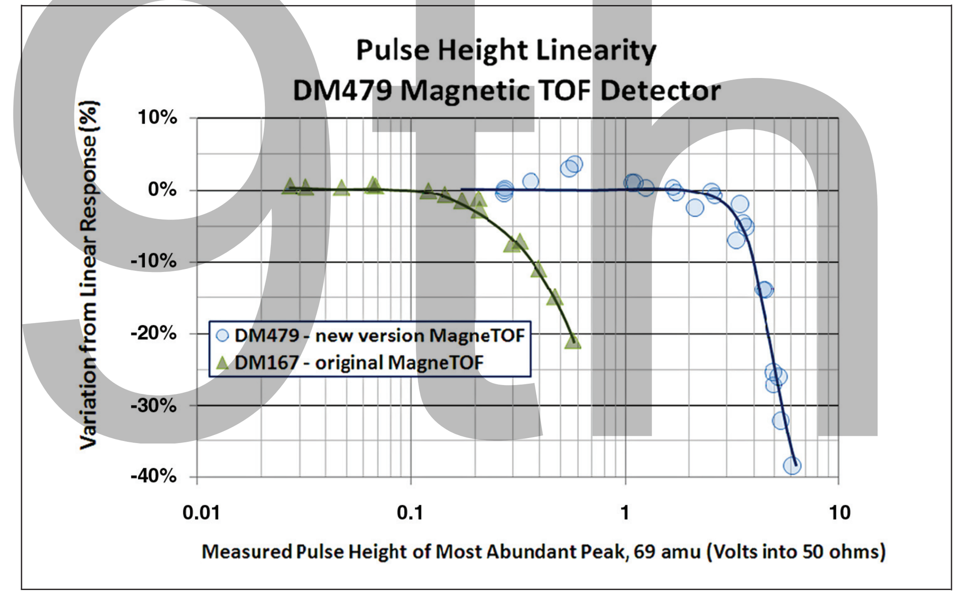

Figure 3. Pulse dynamic range data showing 10X increase in linear response of new version MagneTOF™as compared to the original MagneTOF™.

No Pulse Shape Distortion During Extreme High Level Pulses

The pulse shape of the 69 amu (highest) and 70 amu spectral peaks were measured on a 3 Ghz (analog bandwidth) LeCroy oscilloscope to look for distortions that could occur from space charge or other mechanisms during very high current pulses. It is apparent from Figure 4 that no distortion has occurred. Because the inherent TOF system resolution (~1.5 ns) dominates the multiple ion pulse width at 69 amu, the 70 amu isotope peak was also measured where single ion response reveals an undistorted 0.5 ns pulse width (now dominated by the detector's response time) (Figure 5).

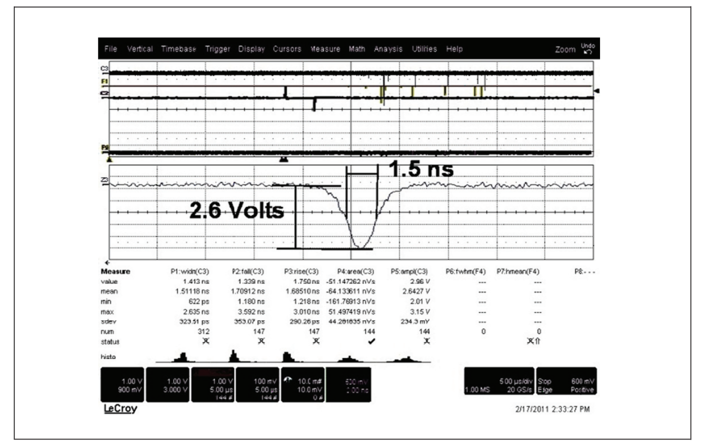

Figure 4. Single shot (no averaging) of most abundant peak (69 amu) showing no apparent pulse shape distortion for a ~2.6 volt, multiple ion pulse. 1.5 ns pulse width is dominated by TOF system's resolution.

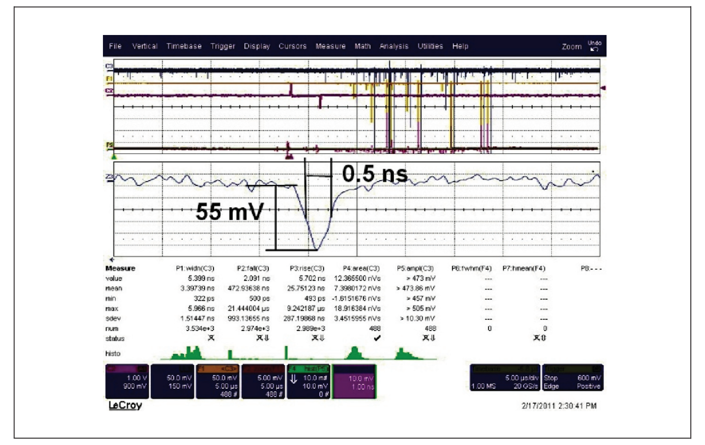

Figure 5. Single shot (no averaging), single ion pulse of 70 amu isotope occurring ~50 ns after most abundant peak (69 amu, ~2.6 volt) showing no apparent pulse shape distortion immediately after a ~2.6 volt pulse.

Gain Recovery After an Extreme High Level Pulse

The same 69 amu peak data (from DM479) shown in Figure 3 is plotted again in Figure 6 along with data collected from the 76 amu peak which occurs ~0.5 microseconds after the 69 amu peak. This enables us to monitor the detector's gain at a time 0.5 microseconds after a major ion burst and hence provides a measure of the detector's gain recovery on this time scale. Because this peak is only 22% of the height of the largest 69 amu peak, it will have minimal impact on the detector's gain and can be seen purely as a gain monitor at this point in time.

Looking at the data resulting from a 5 volt pulse of the 69amu peak, it can be seen that the detector's gain was initially reduced by ~25% during the 69 amu pulse but recovered to a ~10% gain reduction after 0.5 microseconds during the 76 amu pulse.

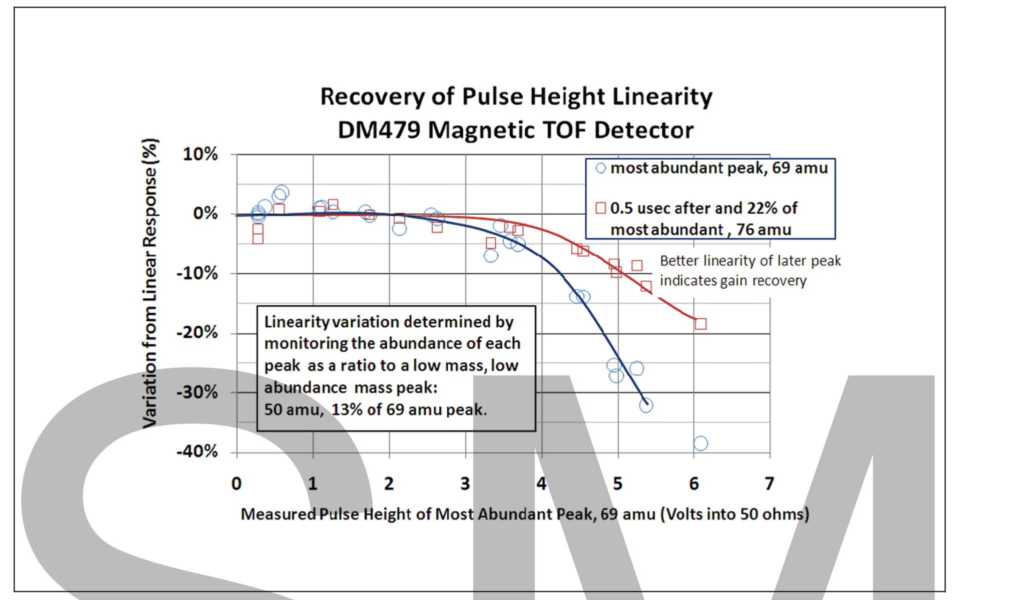

Figure 6. The 76 amu data in this figure indicates the level of the detector's gain recovery during a period of 0.5 μs after the highest (69 amu) peak.

Improved Linear Response for Sustained Currents

The linearity for sustained currents will be different than that for a pulse. The detector relies entirely on the charge stored in its internal capacitance for supplying the output current that is delivered during a pulse. This current is orders of magnitude higher than the bias current flowing through the detector's internal resistance. Although the linearity for sustained currents is influenced by the detector's internal capacitance to some degree, it is actually dominated by the bias current. Because the design changes for the new version detector are most pronounced in the areas of dynode area and capacitance the improvement in the sustained current linearity is considerably less than that for pulse dynamic range and operational life. However, the data in figure 7 shows a sustained current linearity up to ~25 microamps if a 10% over response at high currents can be tolerated.

The sustained current linearity was measured by exposing the detector to a lower flux of ions followed by a higher flux alternatively over periods of many seconds while recording the detector's output. The ratio of high to low flux was controlled by sequentially passing the ion beam through a low transmission (~20%) and then a high transmission grid so that the ion flux ratio remained constant as the absolute ion flux was slowly increased. Essentially the low transmission signal provides a monitor of the ion flux as the flux is increased to the point of distorting the high transmission signal. The data shown in Figure 7 is based on the ratio of these two signals at a variety of ion flux levels.

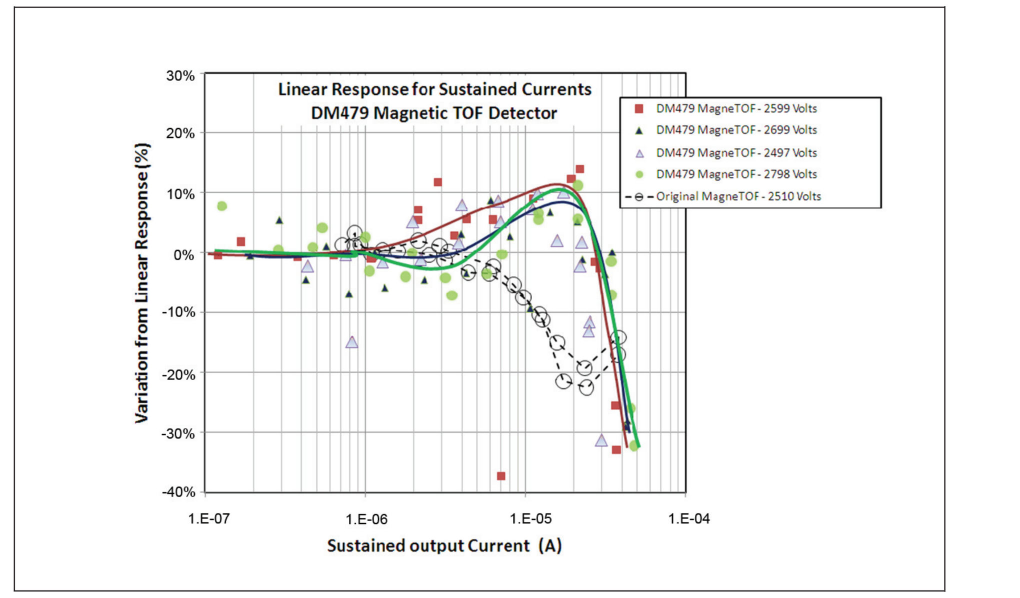

Figure 7. Variation from linearity for detector response when subjected to sustained output currents. Sustained currents up to ~25 microamps are practical if a 10% over response can be tolerated.

Accelerated Aging Test in Realistic Conditions Indicate Negligible Aging after 6 Coulombs of Accumulated Output Charge

It was found that the rate of detector aging is highly dependent on the characteristics of the ions being measured by the detector. Spectral shape, peak pulse height and width, spectrum duty cycle and average ion flux level all have significant influence on the rate of aging. Although a continuous ion beam can provide a highly accelerated aging test it will usually result in a very optimistic and unrealistic result. The orthogonal TOF system described above was employed to achieve an aging measurement under realistic conditions: a system repetitively delivering ions from successive TOF spectra to the detector.

The TOF system was used to continuously monitor the head space vapor above the TRIS sample. The system was operated at 25 khz (40 μs trigger interval) with a spectrum duration of ~15 μs. Feedback was used to continually adjust the detector HV to maintain the most abundant peak (69 amu) at 2.0 V, resulting in ~9 μA average output current. The sample was intermittently injected into the system and the detector HV was then manually adjusted to deliver a detector gain of 10^6 by monitoring average pulse height with a fast oscilloscope. This compensated for the continually decreasing ion intensity (and increasing HV) resulting from the slowly depleting sample and is the cause of the saw tooth appearance of the data (Figure 8).

After 6 coulombs of accumulated output charge the detector has aged only marginally: requiring only 2450 volts to achieve a gain of 10^6, a small fraction of the available voltage adjustment (4000 volts maximum).

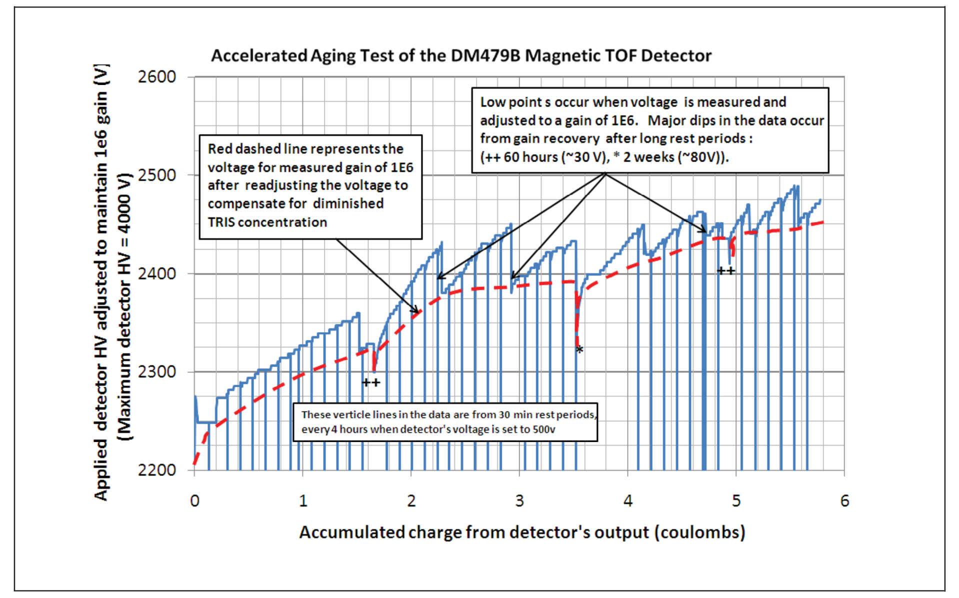

Figure 8. Accelerated aging test results showing minimal aging after almost 6 coulombs of accumulated detector output current.

Conclusions

By looking closely at all the design details of the original MagneTOF™ detector and applying new ideas to various design approaches accumulated from 5 years of field experience, it has been possible to achieve major performance improvements:

- X10 improvement in pulse dynamic range: 2.5 volt linear output pulse
- X10 improvement in operational life: >>6 coulombs accumulated output charge
- >X2 improvement in linear sustained output current: ~25 μA
- No measurable pulse distortion during extreme current (2.6 V) output pulses.