APPLICATION NOTE

ENERGY MEASUREMENT LIMITS USING JOULEMETER PROBES WITH VARIABLE RESPONSIVITY (R_V)

Any measurement instrument has a set of available ranges to use. With instruments that measure voltage, current, or resistance directly, those ranges are easy to understand and easy to implement. Instruments designed to measure the output of a sensor are not as simple. The sensor converts real world phenomena to a measurable signal such as voltage or current. The complexity arises in how the conversion is done. A given sensor may not have a tightly controlled conversion factor, which means the voltage output by the sensor will also not be tightly controlled. The instrument must deal with this when a given range is selected. Imagine an oscilloscope. What would the 1 Volt per division range mean if the probe was not 1X or 10X but some variable value? In the case of Laser Energy Probes, the conversion factor is the responsivity, or R_V, with units of Volts per Joule. The R_V of a given probe is a function of the probe sensor's voltage response, which varies from sensor to sensor, as well as the tolerances of the following integration circuitry. A further complication is the fact that all of the sensors used for Laser Energy Probes exhibit a wavelength dependent R_V to some degree. This means that tightly controlling probe R_V is not feasible, and therefore the output voltages of the probe are not tightly controlled. Simply defining a fixed set of energy ranges will not work.

HOW RANGES ARE CHOSEN

The measurement instrument must configure its ranges based on the available internal voltage gains and the expected voltages from the probe in use. **There is a limit to the amount of voltage the probe can supply as the integration circuit has finite power supply voltage.**

Suppose a probe has an R_V of 1250 Volts per Joule, and can output 10 volts before it runs out of power supply headroom. The maximum energy the probe can output is then 10 Volts divided by 1250 Volts per Joule, or 8 mJ. If the instrument displayed Volts we would choose a 10V range and be done, but the instrument displays Energy and does not have an 8 mJ range. It has a 2 mJ range or a 20 mJ range. This means the instrument must decide which range to use. If it uses the 2 mJ range, then it is artificially limiting the range of the probe.

If it uses the 20 mJ range, then the probe is not limited, but the maximum reading the instrument can display using the probe is still only 8 mJ. It should be clear that even if the instrument was designed to have an 8 mJ range, a different wavelength might result in an R_V of 200 Volts per Joule and we would be faced with the same problem. Gentec-EO Energy Detectors of the Mach 5, QE-I-USB, PE-I-USB and QE-B + DPM Series are designed to not artificially limit the measurement range of the probe. What this means is that, when the reading exceeds 8 mJ, the instrument will display a probe saturation error (SAT) to warn the user that the instrument has reached the voltage limit and the reading is no longer accurate.

We have stated that the energy ranges of the instrument depend on the probe R_V. We can develop a more rigorous approach to show why this is so, and what that dependency is. A probe with a given R_V irradiated by a given energy will produce a voltage equal to:

Eq. 1

$$V_{in} = \text{Energy} \cdot R_v$$

For a given energy range selected by the user, we want to maximize the voltage at the ADC when the maximum energy for the selected range is incident on the probe. The voltage at the ADC is:

Eq. 2

$$V_{ADC} = V_{in} \cdot \text{Fixed Gain} \cdot \text{Variable Gain}$$

Variable Gain is a combination of gains and attenuations used to fine tune the instrument in a given range. Substituting equation 1 into equation 2 gives:

Eq. 3

$$V_{ADC} = \text{Energy} \cdot R_v \cdot \text{Fixed Gain} \cdot \text{Variable Gain}$$

We can see that, for a given R_V, we can choose a Variable Gain value to maximize the ADC input voltage for a full-scale energy inputs. The next question that arises is "What is the maximum energy that can be measured for a given R_V?" We want the full scale energy in a given range to result in the maximum voltage input at the instrument's ADC. Solving equation 3 for the full-scale energy gives:

Eq. 4

$$\text{Energy}_{\text{Full Scale}} = \frac{V_{\text{ADC max}}}{\text{Variable Gain} \cdot R_v \cdot \text{Fixed Gain}}$$

The values of the variable and fixed gains depend on the instrument design and the selected range, but the equation shows that the maximum measurable Energy is R_V dependant regardless of the instrument design. Since R_V itself is wavelength dependant, it follows that the maximum energy and hence the available energy ranges are also wavelength dependant.

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R_V WAVELENGTH DEPENDENCY

Wavelength correction can be done in the instrument gain circuitry or as a mathematical correction after the measurement has taken place.

If the wavelength corrections are done mathematically, then the instrument's internal gains are not modified and the ranges remain unaffected. The measurements are multiplied by the appropriate correction factor. Consider a probe with an R_V of 1000 V/J at a given wavelength. With 1 mJ incident on the probe, it will output a signal of 1V. Suppose the instrument is set to a 2 mJ range and a full scale reading at the ADC is 2V. The ADC will read 1/2 of full scale and the instrument will display 1 mJ as expected. Now suppose the wavelength is changed so that the R_V of the probe is 125 V/J. The same 1 mJ will now result in a signal of 125 mV. The ADC will now read 1/16 of full scale and the instrument would display 125 µJ if no wavelength corrections were applied. With wavelength corrections, a multiplication factor of 8 (1000/125) will be applied so the reading will be 8 x 125 µJ = 1 mJ. The energy can be increased until the full 2V is present at the ADC. At this point the displayed energy will be 16 mJ, even though the range is set to 2 mJ.

If wavelength corrections are done in the instrument gain circuitry, when a wavelength different from the calibration value is selected, the internal gains of the instrument are changed to normalize the response of the probe to the calibration wavelength. Since the sensor responsivity can vary significantly with wavelength, this may cause a rescale of the available ranges. If this occurs, the instrument will set itself to the currently set range if it is still available. If it is not, the instrument will set itself to the next available range.

The first method retains the original ranges, but the readings can be outside the set range and multiplications are required for each measurement which can take up valuable processor time.

The second method maintains range and reading parity, but rescales the ranges to do so. No math corrections are done as the measurements are automatically corrected by the reconfiguration of the instrument gains.

CONCLUSION

An instrument designed to measure a sensor with a fixed output characteristic can use a fixed set of ranges matched to the sensor characteristics. If the sensor output signal has a variable response, then trade-offs must be made in the selection of the available ranges. As a result of this, the maximum available range must be selected to either artificially limit the measurable energy, or allow a range that may allow measurements to the full scale of the range. Gentec-EO Detectors of the Mach 5, QE-I-USB, PE-I-USB and QE-B + DPM Series are designed to not artificially limit the measurement range of the probe. If the energy reading exceeds the measurement range of the probe, then the instrument will display a saturation error.

If you have any questions about this Application Note or the performance of our Mach 5, QE-I-USB, PE-I-USB and QE-B + DPM detectors, please don't hesitate to contact us at info@gentec-eo.com.

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