TECHNICAL NOTE

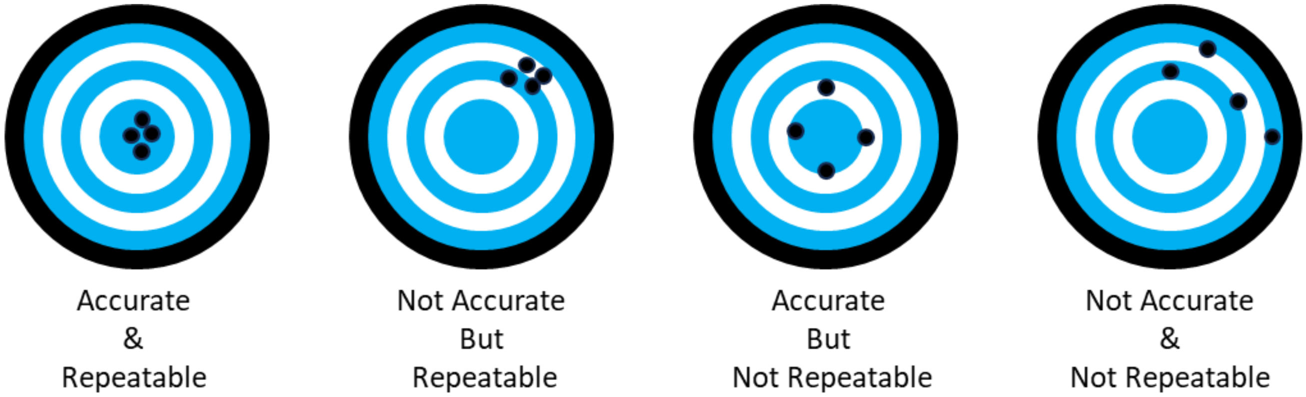
SAME LASER, SAME DETECTOR: A MEASURE OF REPEATABILITY

We often get questions by customers who get unexpected measurement repeatability when measuring the same laser with the same detector multiple times. The purpose of this technical note is to guide you through basic precautions and good practices that will allow you to get the most accurate and repeatable measurements possible using a Gentec-EO power meter. It will also give you tools to help identify the possible sources of the discrepancies between the measurements.

1. WHAT IS MEASUREMENT REPEATABILITY?

Measurement **repeatability**, also sometimes called the precision, is the closeness of the agreement between the results of successive measurements of the same measure when carried out under the same measurement conditions. In other words, it is the variance in measurement results of a single source taken using a single instrument, under the same conditions over a short period of time.

Not to be confused with measurement accuracy or reproducibility. Measurement **accuracy** is the closeness of the measurement value to the true value. The illustration below is often used to help understand both the accuracy and repeatability and depict the distinction between the two.



Reproducibility on the other hand is the closeness of measurement results when using different equipment to measure the same source.

2. THINGS TO VERIFY BEFORE DOING THE MEASUREMENT

1. **Check the specifications:** Make sure that each detector is used within the specified limits. For maximum accuracy, your detectors should be used at ~50% of their capabilities.
2. **Verify the alignment:** Make sure the laser is aligned with the center of the absorbing surface and that all the light is contained within the aperture.
3. **Measure the beam area:** For Gentec-EO detectors, the beam area should not exceed 80% or be less than 10% of the effective area.
4. **Check for damage:** Is there any visual damage to any of the detectors: ablated absorber, scratches, discoloration, grease spots, etc?
5. **Verify the calibration due date:** Check the calibration due date on the calibration certificates of both the monitors and the detectors. Maybe it is time for one of them to be sent back for a recalibration?

3. STEPS TO TAKE WHEN MAKING THE REPEATABILITY MEASUREMENT

1. **Preheat the detector:** Switch your laser on to preheat the detector for several minutes.
2. **Let the detector cool down:** Switch your laser off and let the detector cool down for at least 1 minute.
3. **Zero the detector:** Once the detector has cooled back down, zero the detector.
4. **Switch your laser on:** Switch your laser on for a few minutes to heat the detector back up.
5. **Take the measurement:** Take a power measurement averaging it over 1 minute.
6. **Switch off your laser:** Switch your laser off and let the detector cool down for 1 minute.
7. **Re-zero the detector:** Take a power measurement by averaging over 1 minute. (this is your real 0 and is used to offset your previous measurement)
8. **Repeat for the next measurement:** Repeat steps 4 to 7 for the next power measurement.

4. HOW TO CALCULATE YOUR MEASUREMENT REPEATABILITY

At Gentec-EO, our repeatability specifications are defined as the peak-to-peak repeatability, and represent the maximum variation in measurements obtained from an identical signal. It is calculated as follows:

$$Repeatability = \pm\frac{P_{max} - P_{min}}{2\bar{P}}$$

where:

$$\bar{P} = Average\ power\ measurement$$
$$P_{max} = Maximum\ power\ measurement$$
$$P_{min} = Minimum\ power\ measurement$$

For example, you are measuring the output of your 1 kW laser using Gentec-EO's UP55C-2.5KW-HD-D0 power meter. You make 20 measurements following the steps outlined above and get the following measurement values.

Measurement number	Measured power (W)
1	1008
2	1010
3	1004
4	997
5	996
6	1005
7	995
8	998
9	1002
10	1005
11	1005
12	996
13	997
14	1000
15	1003
16	1002
17	999
18	1003
19	1009
20	1002

To calculate our measurement repeatability, first we calculate the average power.

$$\bar{P} = 1001.8\ W$$

We then identify what are the highest and lowest measurement values within our 20 measurements.

$$P_{max} = 1010\ W$$

$$P_{min} = 995\ W$$

Finally, we can calculate our measurement repeatability:

$$Repeatability = \pm\frac{1010\ W - 995\ W}{2 * 1001.8\ W} = \pm 0.0075 = \pm 0.75\%$$

But wait, Gentec-EO states that the repeatability of the UP55C-2.5KW-HD-D0 is ± 0.5%, so why are my measurements outside of this specification? Keep reading, this question is addressed in the next section!

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5. WHY DOES MY REPEATABILITY CALCULATION SHOW A HIGHER % VALUE THAN THE SPECIFICATIONS GIVEN BY GENTEC-EO?

Many things can affect your measurement repeatability. Often when making a measurement we assume that only the detector specifications should be taken into account. However, we should always consider what and how we are measuring. For example, the stability of your laser source output as well as environmental factors such as temperatures and humidity fluctuations, and optical and electrical noise should be taken into account.

At Gentec-EO, we use state-of-the art facilities and NIST-calibrated reference detectors to minimize these additional factors, giving you the most accurate repeatability specifications for our detectors.

In the above example, we calculated the measurement repeatability, not the detector repeatability. As mentioned, the laser stability will also affect our measurement repeatability, but how do we take this into account? The answer is rather simple, we use the root mean square (RMS) method.

For example, the measurements above were performed using a laser with a specified stability of ± 1%. Assuming this is the only other source of instability in our system. We can calculate our measurement repeatability as follows:

$$Measurement\ repeatability = \pm\sqrt{Detector\ repeatability^2 + Laser\ stability^2} = \sqrt{0.5\%^2 + 1\%^2}$$

$$Measurement\ repeatability = \ \pm 1.12\%$$

We can conclude that our measurement repeatability calculated in the previous section falls within the value we expect given the laser and power meter specification, and that both instruments are working properly!

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