

Application Note

Measuring Laser Position & Pointing Stability

One of the laser's most useful properties is that it can propagate over great distances defining a straight line, and many optical systems are designed to exploit this property. Therefore, beam profilers are often used to verify the performance of lasers and optical systems to avoid problems caused by bad alignment or to streamline the manufacturing processes of these devices. This is often a simple measurement of where in space a laser spot is focused or aimed, which is relevant to a number of laser applications from laser range finding to optical scanning, laser marking to building laser printers. Beam profilers have the capacity to tell where the beam is located on the detector, and different types of profilers can do this with varying degrees of accuracy and precision. Most of the time the measurement is made by placing the beam profiler at some distance from the laser source and aligning the beam until it points to the ideal target. For laser scanning applications the measurement may be made in different locations across the scan plane to ensure proper linearity of the scan. But there is more to this measurement and more that can be learned about the laser's performance.

Laser pointing accuracy and pointing stability are defined as an angular value, usually in milli- or microradians (mr or μ r). Pointing accuracy is simply whether the laser points where it is supposed to. Pointing stability is a measure of how much the beam position drifts from the ideal target over time. Stability can be affected by a number of factors both internal and external to the laser itself, including physical motion, heat buildup, cavity instability, air currents and many more.

There are actually two components to laser pointing and laser pointing stability, the linear and the angular, which combine to affect the beam's position. The linear component comes from the horizontal and vertical motion of the laser, perpendicular to the axis of propagation. We will call this X and Y. This is the motion that one sees when the laser is raised or lowered, translated right or left, or is subjected to some type of vibration. This motion is normally 1:1, that is, if the laser is raised 1mm, the spot moves 1mm unless there is a magnification lens in the optical path¹.

The angular component is the tip or tilt of the laser beam altering the path from the parallel. We call this $d_{\theta x}$ or $d_{\theta y}$. It is possible to design a fairly simple measurement system to separate these two components of pointing. This can be very useful if the measurement's purpose is to determine the stability of pointing in an optical system. It is good to know whether instability is coming from linear motion of the laser or from angular perturbations.

¹ This method can be used to calibrate a magnification system by moving the laser a known distance and comparing the motion at the detector. At a nominal 10:1 magnification one would expect 100 μ m motion of the laser to appear as 1mm at the detector; if it is 955 μ m, then we know that the actual magnification is 9.55:1.

In order to measure the linear and angular pointing, the measurement system will comprise two detectors. The first is set up as a near field profiler imaging the front aperture of the laser via a beam splitter. The other detector in the far field is set up with a lens of a known focal length (e.g., 1 meter) with the detector positioned at the geometric focus. With this system any linear motion of the laser will be detected by the near field profiler, but will not appear in the far field due to the f-theta properties of the lens. Angular changes, on the other hand, will be detected by the laser beam profiler.

Laser Pointing Measurement System

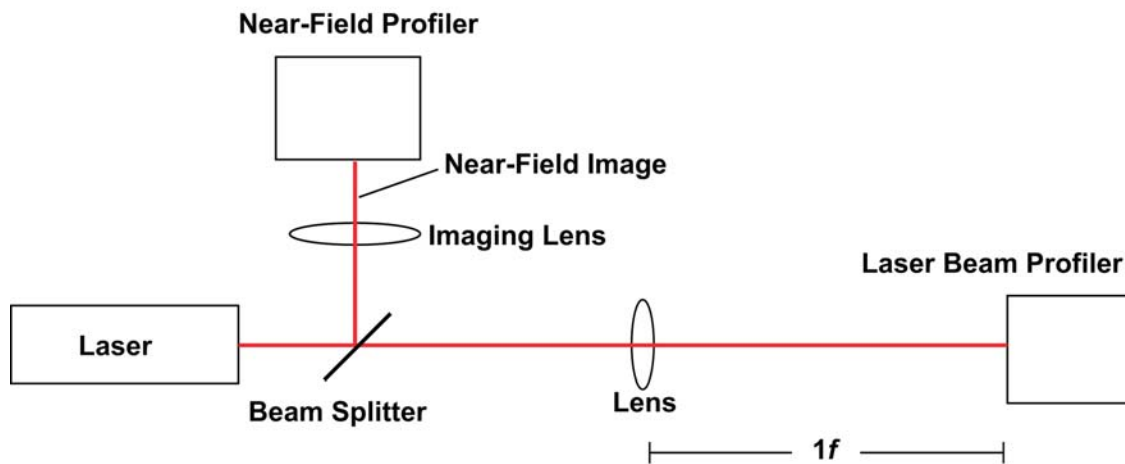


Figure 1: Pointing measurement system to discern angular and linear pointing accuracy

The above described apparatus performs a fairly specialized test. Most people are simply interested in the location of a beam at a certain distance or the pointing accuracy along the axis of propagation. Very accurate beam position measurement is much more difficult than it first appears, because the beam can be affected by air currents or heat waves, which can change the refractive index of the air through which the beam is propagating.

Case Study 1

As an example of this problem a Photon customer called complaining that his focused 21 μ m laser spot was measuring 37% too large and that there must be something wrong with his profiler. After investigating the set up of his laser and measuring system we learned that his laser included a blower to cool the area. We had him turn off the blower, and the spot size returned to within a couple percent of the expected size and was in the proper location. Wind and convection currents from the blower were deflecting and altering the beam. As a result the customer redesigned the cooling system to reduce these effects.

The NanoScan Advantage



The unsurpassed pointing accuracy of the NanoScan allows the entire measurement to be reduced to the bench top. Using scan averaging, the NanoScan can measure pointing to $<100\text{nm}$, which translates to the ability to measure deviations of $<1\mu\text{m}$ on a 10cm test bench.² With this level of resolution very accurate pointing measurements can be accomplished in a small space and with little opportunity for external

forces to impact the measurement. Obviously a 10cm test range is far easier to manage and control than one spanning 100 or even 1000m in length. Manufacturers of range finding and laser sighting products have found that the NanoScan reduces their test time dramatically, leading to high throughput and rapid time to market for their products.

Measuring the pointing stability of the laser is facilitated in the NanoScan software by the use of the time statistics and the accumulate features of the parameters and pointing windows. The pointing window accumulate mode will provide a picture of the amount of excursion seen and in which axes the movement takes place. The time statistics graphs can provide a temporal picture of any instability, *e.g.*, does instability coincide with some other event, such as air conditioning or equipment start-up, the beginning of the swing shift, etc? Using these tools can help get a more complete picture of the sources of instability and provide the information needed to improve the laser system.

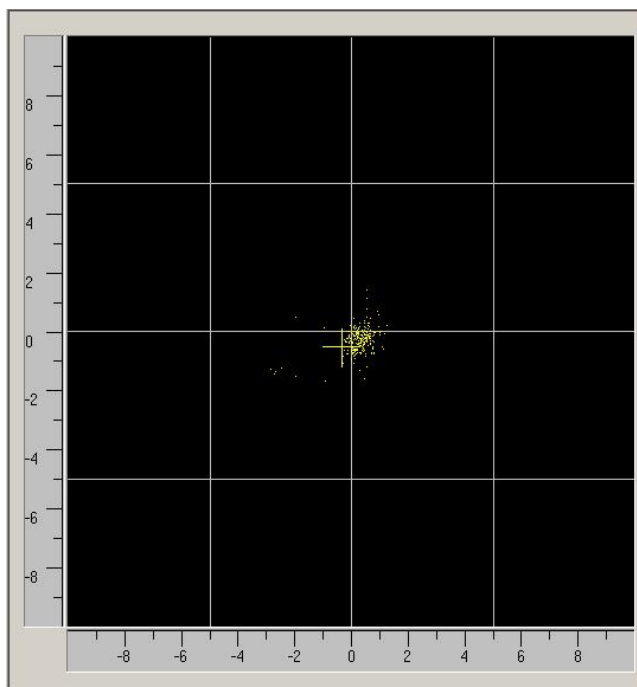


Figure 2: NanoScan pointing screen with accumulate mode

² S.C. Irick, W.R. McKinney, D. Peterman, V.V. Yashchuk, "Performance of Long Trace Profiler Part 5.1: Noise Due to Laser Pointing Instability" *Light Source Notes*, October, 2005; available on the Photon website www.photon-inc.com

Case Study 2

A laser manufacturer customer called in frustration saying his laser pointing stability could not possibly be as poor as he was measuring with his beam profiler. A Photon staff engineer visited the site and found that the beam profiler had been mounted on an old 3-axis stage that was quite loose and unstable. Tightening the stage added considerably stability to the measurements. It was also observed that the laser generated quite a bit of heat, causing variable refractive index gradients and thus beam motion. A simple cardboard tube placed around the laser beam between the laser and the profiler blocked the thermal waves causing refractive index gradients and made the beam much more stable. Once these external contributions to instability were resolved, they could then concentrate on reengineering the laser to improve its inherent stability.

Other Measurement Solutions

Position detectors, such as quad cells and PSDs (position sensitive detectors), have numerous shortcomings. Although quad cells can tell if the beam is centered on the detector, it doesn't easily tell the actual positional error if the beam is not centered. For small beams ($<200\mu\text{m}$) they are essentially useless, because the inter-cell gap is $100\mu\text{m}$. PSDs are better; they have accuracies on the order of 0.1%, but are only capable of handling laser powers of a few milliwatts. They are very fast, analog devices, but all they can do is measure position. If a precise measurement of small changes is required, it may be necessary to make the measurement over a long distance. This long distance has several disadvantages, most obviously the requirement for a large space in which to perform the measurement, but also the long distance range provides ample opportunity for the external influences of air currents and heat waves to alter the beam.

Cameras

Of course it is possible to make these measurements with a camera-based profiler, too. There will be some compromises required due to the need for attenuation and the lower absolute pointing accuracy of the camera systems. Attenuators will alter the beam path, and it will be necessary to make corrections for these if accurate results are to be obtained. The rule of thumb for pointing accuracy in a camera array itself is approximately one-tenth pixel; therefore with the current state of the art CCD and CMOS camera sensors the accuracy will be 0.4 to $0.6\mu\text{m}$. Despite these shortcomings, for low repetition rate pulsed lasers in the visible to near IR wavelength range, this is the only good solution.

Photon can provide both FireWire BeamPro CCD and USBeamPro CMOS camera solutions for this and other applications. The software for these profilers also includes accumulate and time statistics features mentioned above.



USBeamPro



FireWire BeamPro

Goniometric Radiometer

Another application involving a pointing measurement is to check the pointing accuracy of laser diodes mounted in standard packages, such as TO cans (laser diode mounts). Photon's LD8900 series of goniometric radiometers can measure the pointing angle of these divergent devices to less than one quarter degree. The goniometric radiometer measures the divergence angle, theta, for each circular angle, phi. The pointing angle is also measured for each phi; thereby defining the 3-dimensional pointing direction. Ideally this should be straight up, at 0° for each phi angle, but errors in mounting the diode in the device can, and do occur. Identifying this is important to ensure that the devices can be used in the systems for which they were procured.

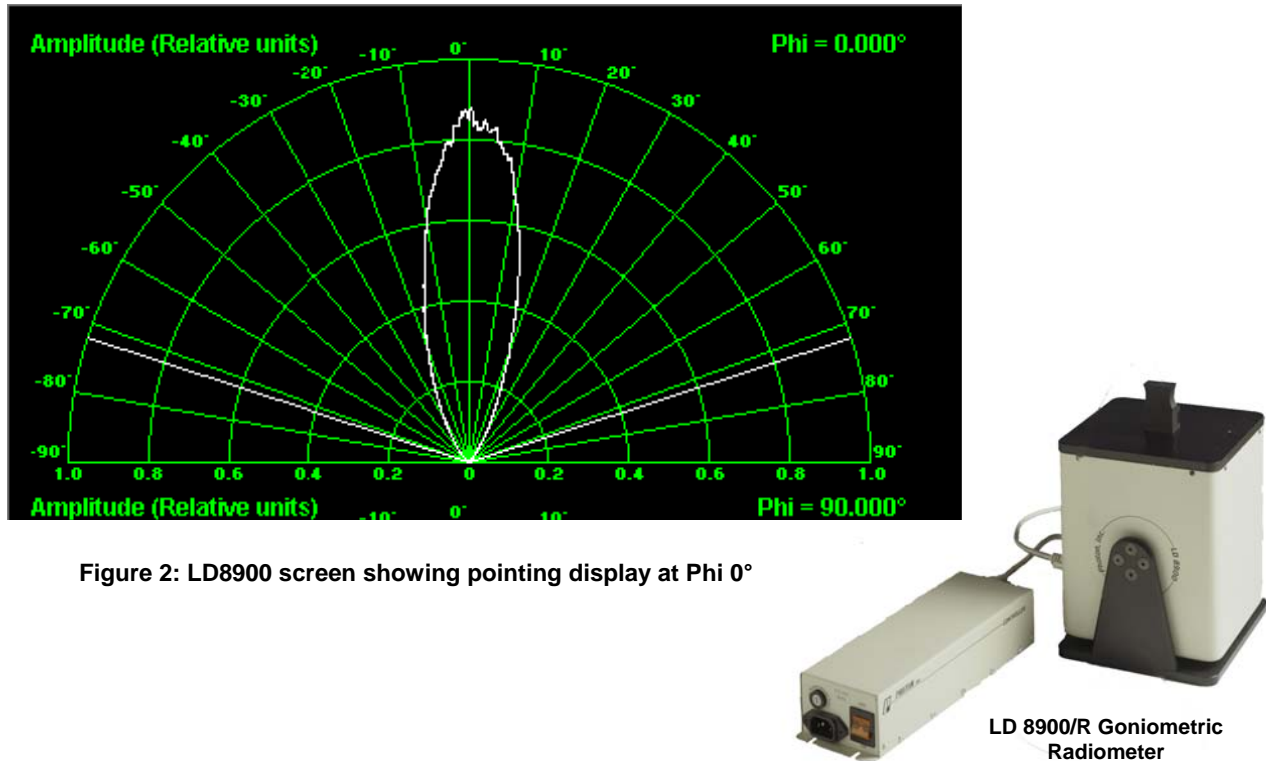


Figure 2: LD8900 screen showing pointing display at Phi 0°

Conclusion

There are many ways to measure laser pointing stability depending on the type of laser to be measured, the level of accuracy required, and the speed and ease of the measurement technique desired. Photon can provide many of these systems and the expertise necessary to match a system to your requirements. In any case a Photon measurement system will provide a quantifiable value for your pointing stability measurements. You will know if your laser system is performing as designed and be able to make corrections if it is not.