1. Fundamentals of Beam Positioning

BEAM-POSITION MEASUREMENT

A unique characteristic of a laser beam is that it propagates through space as a perfect line from point A to point B. Based on this capability, many straightness and positioning devices are available. However, although traveling from A to B is a prefect line, changes in emitted position as a function of time, age, and atmospheric conditions are a known phenomenon. In most cases, this movement is only a fraction of a beam's diameter, but in a long-path this movement can cause problems. Duma Optronics offers systems for measuring beam positioning coupled with special high stability lasers that minimize drift. The basic technologies are: a quadrant detector for centering and alignment, a lateral-effects detector for engineering measurements (deviation in microns), a dual-detector alignment system (AlignMeter) that measures both beam positioning and angular deviation (critical for alignment of long-straight mechanical systems and articulated arms). Large scale movement is provided by a specially designed instrument – SpotOn LA, capable of measuring movement up to 100 mm. For special applications, camera-based systems will simultaneously measure multiple beams, CW or pulsed. The positioning family is offered under the product line of SpotOn. The alignment lasers are offered under LaserOn brand name.

QUADRANT DETECTORS

In certain applications it is necessary to align a laser beam to a target and to maintain the alignment with high precision over long periods of time. To assure that the alignment is kept over a long period of time, an active feedback loop maintains the alignments by nulling the beam to the center of the target. The best detector to use for this application is the 4-Quadrant detector because the center of a quadrant detector does not change with time or temperature. Nulling is controlled by a computer that processes the signals from the detector and adjusts a pointing mirror to re-center the beam. One of the most important features of a 4-quadrant detector is the gap between the detectors – common gaps are 10 and 30 microns, although better gaps could be supplied.

The quadrant detector is a uniform silicon disk a cross gap in between. Consequently, there are four equal photo detectors encapsulated as one. The center of the detector is the intersection created by the cross-like separation. A laser beam centered on the detector will generate equal currents from each segment. Beam movement will be translated into different current on each segment and by processing this data the fluctuation of the beam center could be calculated. The calculated fluctuation is given as percentage of movement relative to the beam size. Knowing the beam size can facilitate translation into engineering units. The software provided by the SpotOn family is adequate to perform these calculations.

Figure 1 illustrates the geometry of the quadrant and lateral-effect detectors.

In the quadrant detector, the four segments are represented by letters A, B, C, and D.

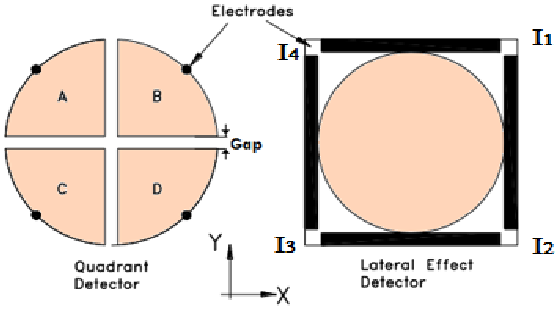

Figure 1

PSD – POSITION SENSITIVE DETECTROS

This family of detectors will display the centroid position of incident laser beams, and will find a large field of applications in the industrial, optical, alignment and general laser quality assurance. For engineering position sensing, three types of detectors are widely used: the dual-axis lateral-effect detector, and mosaic types of detectors like CCD and CMOS. Lateral-effect detectors work in a similar way to quadrant-detectors, wherein information is delivered by four electrodes – two for each axis, and are attached to the back of the sensitive surface. In this case, the four currents are generated by photo absorption and further processed with the appropriate algorithm to give the *x* and *y* positions. In mosaic systems, the beam position is determined by measuring the amount of energy delivered to each pixel on the detector surface. For details of position sensing devices, please use Duma's SpotOn line detailed specifications.

FORMULAS FOR POSITION SENSITIVE DEVICES

Lateral Effect detector

The dual-axis lateral effect detectors have four electrodes attached to the detector, and the four currents generated by photo absorption are processed with the appropriate algorithm to give the X and Y positions. The electrodes are connected such that opposite pairs yield photocurrents which can be processed by an algorithm to give unique displacement values in the X and Y directions. Traditionally, the algorithm has been performed with fixed electronic circuitry and the positions have been accurate to a few percent. Most lateral effect diodes exhibit linearity within 0.5% over the central area (25% of active area), and 3% linearity out to 75% with 5% on the periphery.

The *SpotOn* family, however, has a software, controlled algorithm, which uses calibration corrections stored in memory to linearize the detector response and obtain a precision calibration across the entire sensing area.

This linearization feature implies that the dual -axis lateral effect detector can be used to measure the position of a beam over its entire surface, at a fraction of a cost of comparable detectors with similar linearity. Because each lateral effect detector has a unique set of correction factors for linearization, each system is a matched and serialized set consisting of a detector head, plug-in computer card and linearized software. If a detector head is used with a card or software that is different from the ones with which it was provided, the system will no longer be calibrated.

$$X = \frac{(I_1 + I_2) - (I_3 + I_4)}{I_1 + I_2 + I_3 + I_4}$$

$$Y = \frac{(I_1 + I_4) - (I_2 + I_3)}{I_1 + I_2 + I_3 + I_4}$$

Four quadrant detectors

The equations used to describe the X and Y displacements of the beam are the following:

$$X = \frac{(b + d) - (a + c)}{a + b + c + d}$$

$$Y = \frac{(a + b) - (c + d)}{a + b + c + d}$$

Where A, B, C, and D are the currents generated by each of the four segments. These equations are only meaningful when the beam overlaps all four segments.

If the beam only overlaps two segments, the equations will be unable to provide either the X or Y coordinate information. For example, if the beam only overlaps segments A and B as shown in the following figure, no signal will be generated by segments C & D.

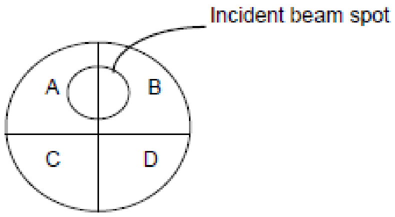

Figure 2 - An Incident beam only overlapping segments A and B

It is clear from the second figure that regardless of the vertical position of the beam, Y will always equal unity if only segments A and B are illuminated. Thus, only the X coordinate will have meaning in this case.

The equations are also dependent on the shape of the incident beam.

Consequently, the photocurrents become nonlinear with displacements of more than about 10% of the beam radius. Thus, the major utility of the quadrant detector is in systems where a beam must be aligned or centered to an optical axis. It is especially useful in feedback systems where the small displacement information from the quad cell is used to realign a laser beam. It is also useful where it is necessary to monitor and measure small displacements over long periods with high stability.

CCD POSITIONING SENSOR

A CCD sensor is a device that converts an optical image into an electronic signal. In positioning applications a special calibrated CCD device is used to convert laser energy into changes sensed by the CCD sensors. A CCD image sensor is an electronic device, built as a two dimensional array of small detection elements regarded as pixels. Pixel size of today sensors vary from about 2microns to above 10 microns and the number of pixels per each sensor can exceed 20 million pixels. When light strikes the chip it is held as a small electrical charge, proportional to the light intensity level, in each photo sensor. The changes are converted to voltage, one pixel at a time, as they are read by the chip. Additional circuitry in the camera converts the voltage into digital information. For positioning applications the CCD detector has to be extremely uniform and convert the incoming light level linearly to its local intensity. That is not the case with regular video cameras using CCD detectors. Further electronics converts the voltage information on each pixel into digital information and streams that information to an USB port. A software algorithm converts the streamed data into positioning information to be displayed by special software. CCD detectors have a clear advantage for pulsed applications when compared with other detectors. Position resolution is usually limited by sensors pixel size. Neither technology has a clear advantage in position applications and should be assessed on a case by case study. Positioning detectors are used as building blocks for a variety of instruments offered by Duma Optronics such as AlignMeter, AngleMeter, Electronic Autocollimators and other application oriented instruments.

APPLICATIONS OF POSITION-SENSING DETECTORS

Laser Testing

Laser manufacturers frequently use PSDs to characterize their collimated lasers.
Using a PSD one can test the absolute power and power fluctuations of the laser, as well as the beam drift, centration, and alignment of the beam to the outer housing or tube. The **SpotOn** is particularly well suited to this application since it provides both a **graphic target display** for tracking the movement of the beam and a **chart display** that enables monitoring of beam characteristics over time.

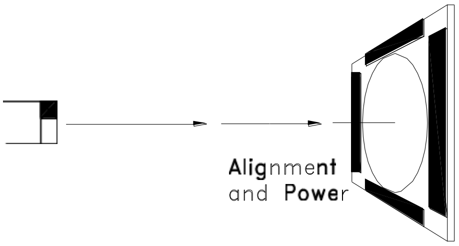

Figure 3

Controlling Optical Beam Alignment

In certain applications it is necessary to align a laser beam to a target and to maintain the alignment with **high precision** over long periods of time.
To assure that the alignment is kept over a long period of time, an active feedback loop maintains the alignments by nulling the beam to the center of the target. The best detector to use for this application is the 4-Quadrant detector because the center of a quadrant detector does not change with time or temperature. Nulling is controlled by a computer that processes the signals from the detector and adjusts a pointing mirror to re-center the beam (see figure 4).

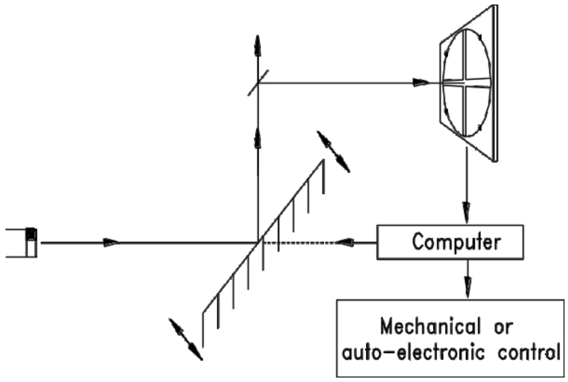

Figure 4

Measuring Linear Displacements

A laser is directed to a moving mirror or a retro reflector. The measuring detector is placed to receive the reflected beam. Moving the mirror target parallel to the original position will generate a linear displacement on the detector surface thus enabling a non-contact measurement of the mirror linear displacement.

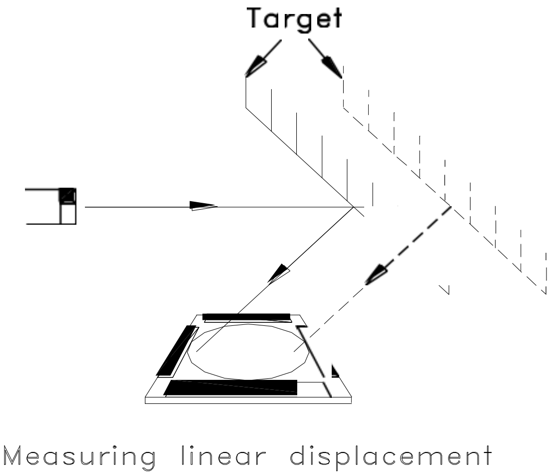

Figure 5

Measuring the Straightness in a gun barrel

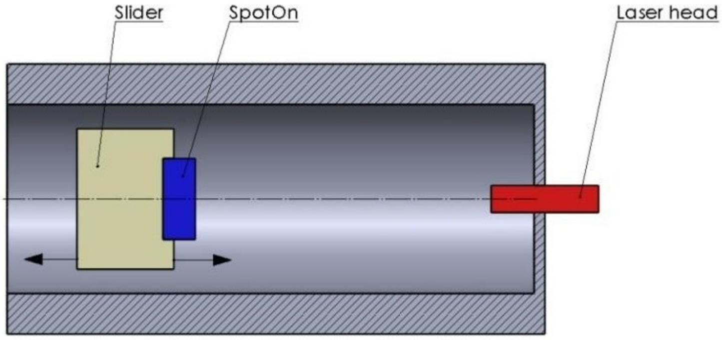

Figure 6

A **SpotOn** system is mounted on a guide way, having the gun's caliber. A laser attached to the gun breech is directed to the **SpotOn** detector creating a **straight** optical path. As the guide way moves, the readings of the detectors will change according to the barrel deformation.

Measuring Errors in Slideways

When used in conjunction with a laser, a dual-axis lateral-effect detector can measure tolerances and errors in mechanical devices with high precision. To measure errors in slide ways, a lateral-effect detector is rigidly mounted perpendicular to the length of a traveling carriage, and a laser is aligned to the detector to define a straight optical path. As the carriage moves along the slide ways, the lateral-effect detector measures changes in the position of the laser beam in two axes perpendicular to the direction of motion. Any changes in beam position readings will indicate deformities in the rails; play in the bearings, or both. In cases where long travel is expected and/or strain induced by the detector head cable is not tolerable, the PSD can be replaced by a later-displacement, hollow retro-reflector. In this arrangement, the detector is mounted parallel to the laser, and light is reflected back into the PSD. Because of the retro-reflection effect, the beam position readings will be twice the actual movement of the carriage. Similar PSD based metrology systems can be used to measure characteristics such as surface flatness, squareness, and straightness.

Configuration for measuring errors in slideways, using a retro-reflector:

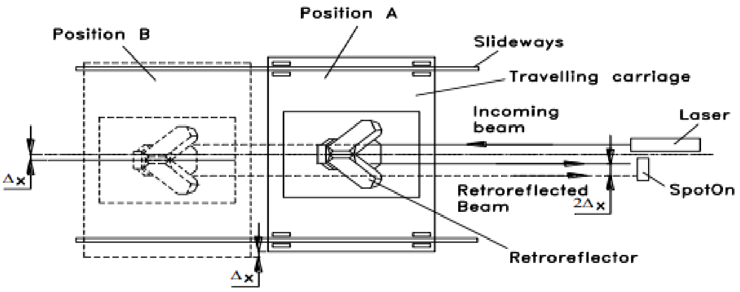

Figure 8

Measuring tolerances and errors in mechanical devices with high precision and in real time will result into better performance. To measure errors in the laser path a lateral-effect detector is an excellent solution. Rigidly mounted to the working area, the detectors will improve and control the beam delivery to the highest accuracies. As the carriage moves along the slideways, the lateral-effect detector measures changes in the position of the laser beam in two axes perpendicular to the direction of motion. Any changes in beam position readings will indicate deformities in the rails, play in the bearings, or both.

Figure 8 describes the application setup with a retroreflector, wherein Figure 9 describes the layout for direct measurement of XY table setup.

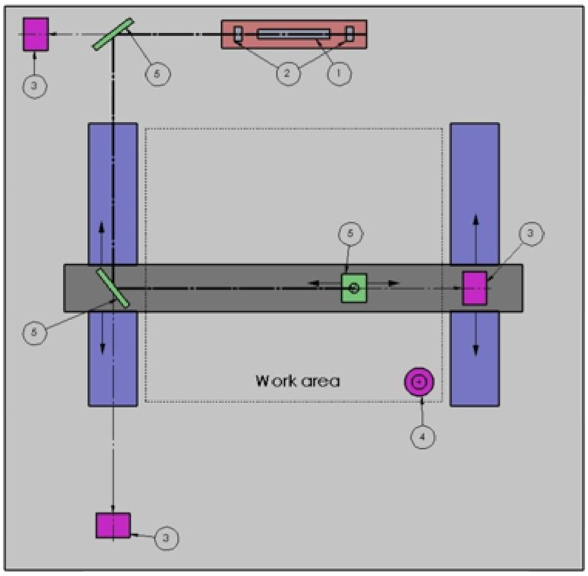

Figure 9 (see table)

No.	Description
1	Laser Rod
2	Cavity Mirrors
3	P.S.D
4	P.S.D – Homing position
5	Folding Mirror

During the use of the laser, the mirrors can shift slightly so regular checking (and adjustment) of the mirror alignment is necessary using data from detectors denoted as number 3, further more a zeroing point denoted as detector 4 will enable periodical adjustment.

With the use of a laser - materials can be cut or engraved. Depending on the power of the laser and the speed of more or less power which is applied to the material. This can result in surface burning or melting of the material (engraving) or completely cut material. Using built in or periodically checking, the laser beam path can significantly improve the overall system performance.