Fundamentals of Beam Positioning

Position-sensitive detectors (PSDs), which detect and record the positions of incident light beams, find application in the analysis of light sources and industrial alignment of machinery and targets (when used in conjunction with a laser).

Three types of detectors are used for sensing the position of the centroid of a beam in the x-y plane orthogonal to the optic axis: the quadrant detector, the dual-axis lateral-effect detector, and camera-based detectors (CCD or CMOS). In the case of the quadrant and lateral-effect detectors, four electrodes are attached to a large-area silicon detector, and the four currents generated by photoabsorption are processed with the appropriate algorithm to give the x and y positions. In the camera-based systems, the beam position is determined by measuring the intensity of light impinging on each pixel. The quadrant and lateral-effect detectors are discussed in more detail in the next paragraphs. Camera-based detectors are available from CVI Melles Griot in 1/2-inch (CCD) or 1/3-inch (CMOS) formats.

QUADRANT DETECTORS

The quadrant detector is a uniform disk of silicon with two 10-μ-wide gaps across the surface. Thus, there are four independent and equal photodetectors on the sensing surface. The center of the detector is known very accurately since it is the mechanical intersection of the two gap lines and does not change with time or temperature. A symmetrical laser or other optical beam centered on the detector will generate equal photo currents from each of the four sectors. If the beam moves from the center of the detector, the currents from the four sectors will change, and the processing algorithm will give the x and y displacements relative to the center.

Figure 11.11 illustrates the geometry of the quadrant and lateral-effect detectors.

In the quandrant detector, the four sectors are represented by letters A, B, C, and D.

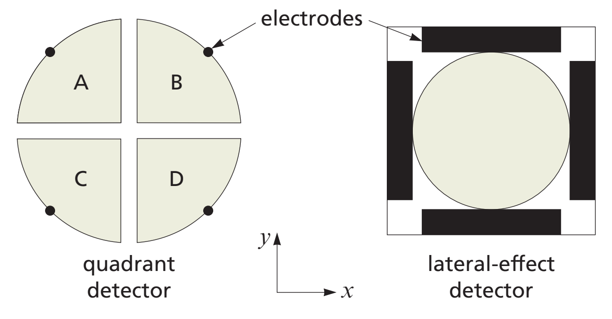

Figure 11.11 **Physical configuration of the quadrant and lateral-effect detectors**

The equations used to describe the x and y displacements of the beam are the following:

$$x = \frac{(b+d)-(a+c)}{a+b+c+d} \qquad y = \frac{(a+b)-(c+d)}{a+b+c+d} \tag{11.15}$$

where a, b, c, and d are the currents generated by each of the four sectors. There are two significant restrictions on the motion of beams used with quadrant detectors. First, to give x-y data, the beam must always overlap a portion of all four sectors. Second, there is only meaningful absolute position information for small displacements of the beam.

The limits of the 8-mm-clear-aperture CVI Melles Griot quadrant detectors are illustrated in figure 11.12.

As shown, if a beam is 2 mm in diameter, its center can move a maximum of 1 mm in any direction before it no longer overlaps all the quadrants. Therefore, the center of the beam must remain within a 2-mm-diameter circle, centered on the detector. The motion of beams larger than 4 mm in diameter is restricted by the clear aperture of the detector rather than the quadrant overlap requirement. Consequently, the center of a 6-mm-diameter beam can only move 1 mm in any direction without moving outside the clear aperture and losing part of the signal.

Because most laser beams are circular with Gaussian intensity distributions, the photocurrents become nonlinear for displacements of more than about 10 percent of the beam radius. Therefore, absolute x and y coordinates become unreliable for beam displacements that are greater than the "measuring limit" shown in figure 11.12.

Because of these two restrictions, the quadrant detector is most useful in systems where a beam must be aligned or centered to an optical axis. It is especially useful where it is necessary to monitor small displacements over long periods with high stability. In feedback systems, displacement information from the quadrant cell is used to realign (null) a laser beam.

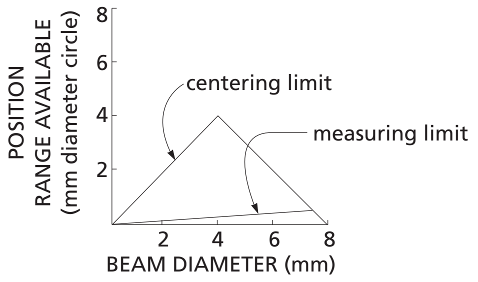

Figure 11.12 **Beam size vs position range for our quadrant detector**

DUAL-AXIS LATERAL-EFFECT DETECTOR

The dual-axis lateral-effect detector uses a doped disk of silicon with four electrodes connected around its perimeter. Opposite pairs of electrodes yield photocurrents that can be processed to give unique values of x and y displacement.

Traditionally, the algorithm has been performed with fixed electronic circuitry, and positions have been accurate to a few percent. The CVI Melles Griot lateral-effect detector employs a software-controlled algorithm and stored calibration corrections to linearize the detector response across the entire sensing area. Unlike the quadrant detector, the dual-axis lateral-effect detector can be used to measure accurately the absolute position of a beam over its entire surface.

Figure 11.13 illustrates the position-measurement limit for the 8-mm-diameter CVI Melles Griot dual-axis lateral-effect detector system. In contrast to a quadrant detector, very small beams can move over the entire 8-mm-diameter surface of the lateral-effect detector. However, because a beam must remain entirely within the area of the detecting surface, larger beams have a limited range of travel. For example, the centroid of a 4-mm-diameter beam must remain within a 4-mm-diameter circle centered on the detector.

Because the lateral-effect detector can accurately measure beam position across its entire surface area, it is frequently used to measure large relative motion of beams and machinery.

APPLICATIONS OF POSITION-SENSING DETECTORS

Position-sensitive detectors (PSDs) are used in numerous laboratory and industrial applications to measure displacements of one form or another. Figures 11.14 through 11.18 illustrate typical setup configurations. In the manufacturing process they characterize lasers and align optical systems. When used in conjunction with lasers they can be used for industrial alignment, calibration, and analysis of machinery.

The following PSD applications are intended to provide examples; they are not meant to be definitive. It would be impossible to list all the uses of these devices. Contact an applications engineer at your nearest CVI Melles Griot office for assistance in evaluating your application's requirement for PSDs.

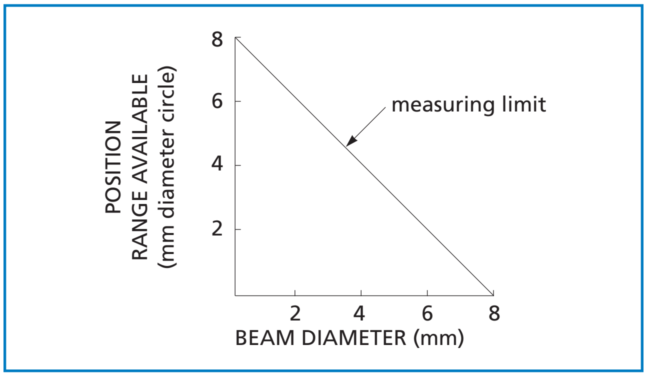

Figure 11.13 **Beam size vs position range for an 8-mm-diameter dual-axis lateral-effect detector**

Laser Testing

Laser manufacturers frequently use PSDs to characterize their collimated lasers. Using a calibrated beamsplitter and two PSDs in the arrangement shown in figure 11.14, one can test the absolute power and power fluctuation of the laser as well as the beam drift, centration, and alignment of the beam to the outer housing or tube. The CVI Melles Griot position-sensing detector systems are particularly well-suited to this application since they provide a graphic target display for tracking beam movement, and a strip chart display to monitor beam characteristics over time.

Measuring Errors in Slideways

In conjunction with a laser, a lateral-effect detector can measure tolerances in slideways with high precision (see figure 11.15). The detector is rigidly mounted perpendicular to a traveling carriage. A laser is aligned to the detector to define a straight optical path. As the carriage moves along the way, the detector measures beam position changes in two axes perpendicular to the direction of motion. Changes in beam position indicate deformities in the rails, play in the bearings, or both.

Where long travel is expected, and/or strain induced by the detector head cable is not tolerable, the PSD can be replaced by a corner-cube retroreflector. The detector is mounted parallel to the laser, and light is reflected back into the PSD. Beam position readings will be twice the actual carriage movement. Similar PSD-based metrology can measure characteristics such as surface flatness.

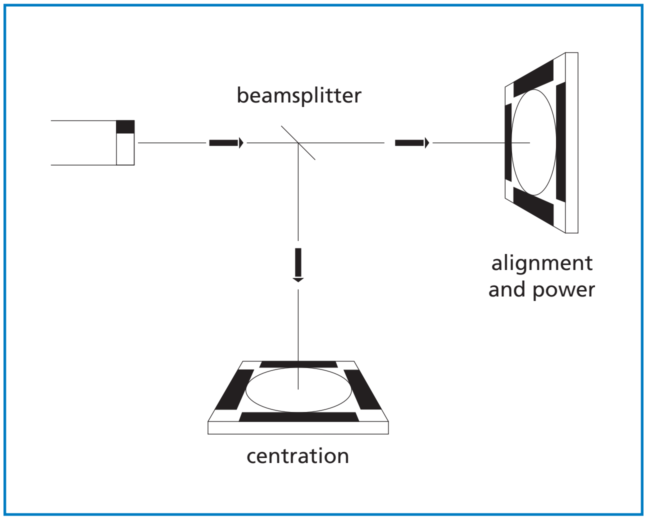

Figure 11.14 **Monitoring laser power, centration, and alignment**

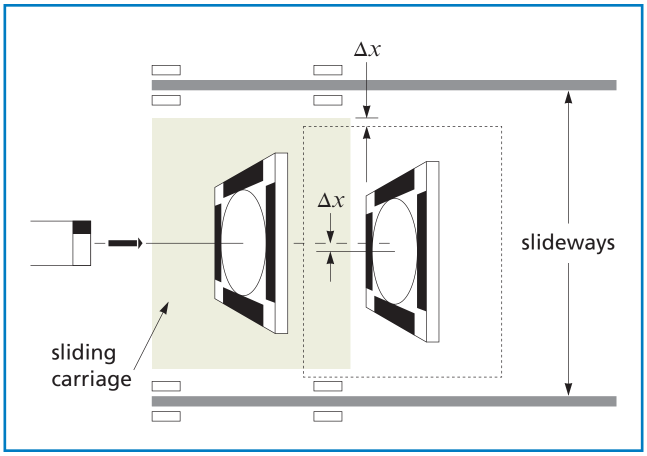

Figure 11.15 **Measuring errors in slideways**

Measuring Roller Parallelism

In industries where materials such as textiles and paper are roll-fed, roller parallelism can be crucial. A laser and a PSD are often used to align and measure this parallelism (see figure 11.16). A laser is mounted onto a V-block with two bubble levels. The V-block is placed on the first roller and leveled in two axes. A PSD with an attached focusing lens is aligned (nulled) to the laser beam, and the V-block is transferred to the second roller, which is then adjusted so that the laser beam is nulled to the PSD. After alignment, the rollers are parallel. The difference between the beam position reading from the first roller and that from the second roller can be divided by the focal length of the lens to yield the angular accuracy of parallelism in radians.

Controlling Optical Beam Alignment

In certain applications it is necessary to align a laser beam to a target and maintain the alignment with extreme precision over long periods of time (see figure 11.17). An active feedback loop maintains alignment by nulling the beam to the center of the target. Quadrant detectors are often used as the target in such applications because the center of a quadrant detector does not change with time or temperature. The high resolution and accuracy of the quadrant detector senses even small drifts of the beam away from center. Nulling is controlled by a computer that processes the signals from the detector and adjusts a pointing mirror to re-center the beam. Because CVI Melles Griot quadrant detector systems provide beam position information in real time, such alignment can be maintained with high precision and stability.

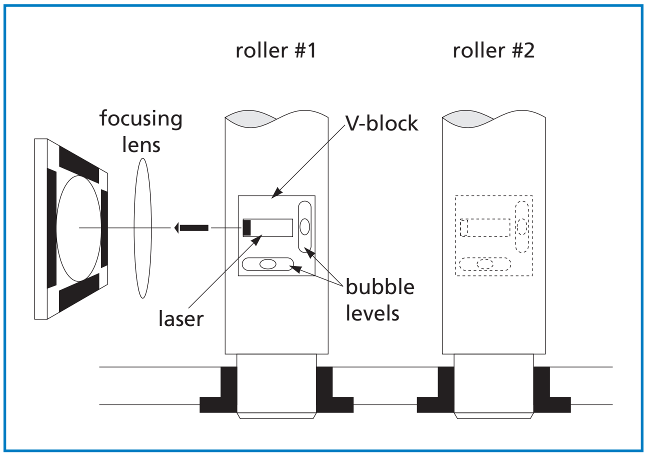

Figure 11.16 **Measuring roller parallelism**

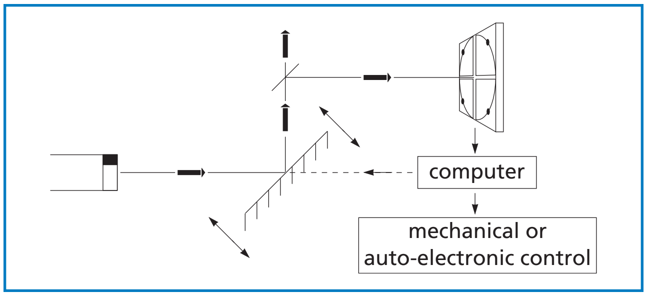

Figure 11.17 **Controlling optical beam alignment**

Other Measurements

PSDs can be used in many more measurement applications, including rotation measurement, linear displacement, and vibration analysis, as shown in figure 11.18.

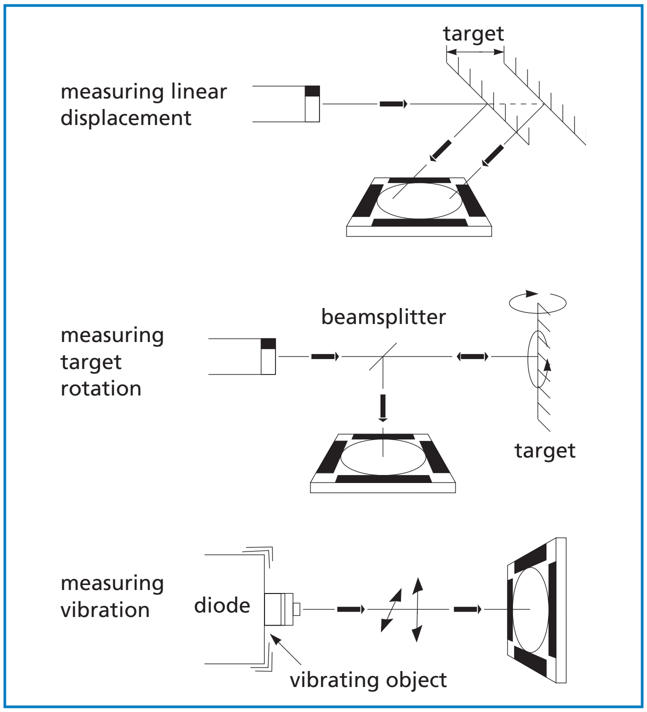

Figure 11.18 **Other types of measurements**