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Measurement accuracy of lateral-effect position-sensitive devices in presence of stray illumination noise

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Abstract

Photodetectors and position-sensitive detectors (PSDs) are widely used in environments where several other light sources also coexist. These randomly arising illumination noises may fall on the detector surface in different spatial distributions and produce unpredicted variations in the PSD output. In this paper, we first describe these stray noises with respect to the operation of PSDs. Then we study and model how the presence of the spurious sources modifies the measurement accuracy of these detectors. The experimental results obtained for the position measurement accuracy while using PSDs and signal beams along with the spurious sources are presented. The experimental data is compared with the results from the proposed mathematical model and it is seen that measured accuracy is within a fraction of a percent of the calculated one. The analysis of systematic errors encountered during data collection is also presented.

Keywords: Position-sensitive detector; Accuracy; Background noise; Lateral-effect

1. Introduction

Photodetectors and position-sensitive detectors (PSDs) are widely used in environments where several other light sources also coexist. In these conditions, PSDs and photodiodes are in presence of increased background optical noise derived by direct and indirect exposure, which include back-scatter reflections from various surfaces. An example of such conditions is shown in Fig. 1, with optical profilometry equipment arranged in auto industry. Some of the light sources, especially lasers, may even have flying or rotating beams of sufficient energy. Thus the expected response of PSDs and photodiodes may be severely disturbed *by undesired signals and background noise*. This paper, focusing on the various sources of external noise for PSDs attempts to analyze various stray beams and *illumination* that may effect the dependable operation of PSDs. We also see how will the PSD react and how these effects may be modeled.

Such random illumination noises may take the form of different sources, e.g. directional, point or extended; and may fall on the detector surface in different shapes or spatial distributions. They may produce unwanted effects while mixing with the real signal, which is coming direct from the source or via the reflector onto the detector surface. These noise sources have been mentioned or described by some of the earlier authors [1–4]. Nonetheless, it is felt that a detailed operational analysis is still required.

It may also be mentioned that for more critical measurement applications, modulation of light source is used to avoid the effects of background light. But on the other hand, such systems become unfeasible in many normal practical applications due to the practical reasons of needed compatibility with simpler light sources, reduced technical complexity and lower system cost. Thus a whole lot of industrial position measurement systems are still produced and utilized with continuous light sources [5,6]. Also important is the fact that, as given by Makynen and others [1], even the modulated-light reflected-beam sensors do suffer from stray *illumination* problem in the form of unwanted reflections from close-by objects. He has outlined this problem along with an effort for a solution. Thus the position response

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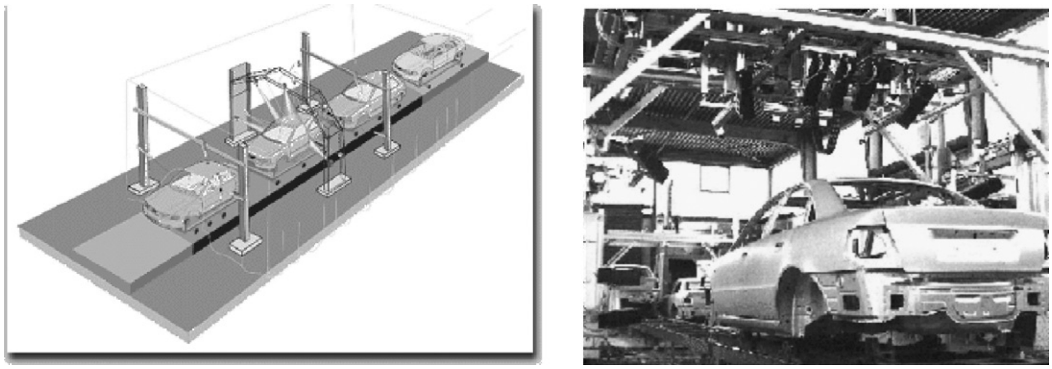

Fig. 1. Simultaneous use of multiple closely-placed laser beams in industrial environments (Photo courtesy Steinbichler Optotechnik GmbH, Germany).

analysis presented here does also apply to these modulated-light sensors, while considering such stray reflections from close-by objects.

2. Measurement accuracy of PSDs

Among the two major types of PSDs, lateral-effect photodiodes (LEPs) and quadrant detectors (QDs), LEPs have the continuous construction in terms of their light-sensing area, which characterizes them from the other segmented detector type. Simply speaking, their construction is in the form of a single continuous photodiode. As the light falls on a specific portion of LEP, the generated current carriers are divided between the extended edge electrodes on each side in proportion to the encountered respective conductance [2].

For these lateral-effect devices, important features include position measurement of the incident light spot for the larger dynamic range or upto the edges of the devices. Additionally, the transfer characteristic for the light spot position measurement has very good linearity for the entire range [1]. The position is measured for the centroid of the incident light beam indifferent to the spot size and shape [7]. The final position along *x*-axis measured from the center of the detector is given as following for the general duo-lateral and tetra-lateral lateral-effect PSDs [8,9]. Similar equation will be used for the *y*-axis position calculation in a dual-axis PSD.

$$P_x = \frac{L}{2}\left(\frac{i_2 - i_1}{i_2 + i_1}\right) \qquad (1)$$

Position resolution of a PSD can be defined as the minimum displacement that can be resolved by a position sensor, while accuracy is the closeness of its position output to the actual beam position in a given electro-optical system. These are important properties of the sensing system as they more or less characterize the quality of the sensing response of the system for smaller signals or displacements. Presence of noises and degradation of signal-to-noise ratio heavily hampers these parameters. Similar to this, the presence of external illumination noises is going to affect the overall measurement accuracy or the tolerance band associated with the measured output.

The overall accuracy of a lateral-effect PSD is affected by both internal factors and external factors. The major spot position uncertainty due to the internal factors can be expressed in terms of speckle noise and thermal noise [10]. According to Beraldin et al, [10] in the system what limits the performance and measurement accuracy of PSDs is the presence of external factors or non-signal spurious lights, which cannot be isolated from the actual light spot position information and are inevitably interpreted as a valid signal by the PSD.

3. Stray illumination noise

Background radiation is probably the most obvious source of external noise in an optical system. The background radiation may be coming from different types of sources and may be taking different shapes and characteristics. Considering the sources of *illumination*, the major sources have been described by Beraldin et al [10] to be ambient illumination, direct sunlight and other laser sources. These sources have been described to be the limiting factors for the fluctuation-free performance or measurement accuracy obtained from the operation of the continuous or lateral-effect PSDs [10]. In the following, we categorize them according to their characteristics and the spatial distribution of their light on the PSD surface, and also analyze them one by one from the point of view of the normal operation of PSDs and the disturbances caused by them.

At least black-body radiation will be falling on each detector from the background present at a specific temperature during the operation or measurement, even if specific sources are not present to emit any disturbing radiation. According to Plank's law, this minimum background radiation illuminating any detector, or a PSD to be specific, is given here for reference purposes as following [4]; while other variations of the formula are also used [11]. Here optical power of background *illumination* is given as the frequency-band integral of light intensities multiplied with area and related solid angle. Unless their intensity is high, their usual effect may be insignificant and smaller but similar to other diffused *illumination* to be described hereafter:

$$\langle P_{\rm opt}\rangle_{\rm BG} = \int_{\Delta\nu} \frac{1}{4} I(\nu)\,{\rm d}\nu\, A_{\rm det}\frac{{\rm d}\Omega}{4\pi} \qquad (2)$$

For our analysis, probably the major source of disturbance can be that from other directional laser beams falling on the surface of a lateral-effect PSD simultaneously. Similarly, other directional light beams and non-laser lights, which fall on the detector surface in a shape approximating a beam, may also be