777 Zapata Drive
Fairborn, OH 45324-5160
+1 937.318.2440 Fax: +1 937.318.2445
www.laserlinc.com info@laserlinc.com

Lump and Neckdown Detection
Using Scanning Laser Micrometers

Introduction

A flaw is a short-term anomaly in the product. A lump is an oversized flaw; a neckdown is an undersized flaw. To detect a flaw, one or more scanning laser micrometers are used to measure the product diameter. The diameter is compared to upper and lower specification limits, the previous measurement value, or both. When a new measurement value exceeds one of these limits or differs from the previous value by more than a specified amount, the system tags the measurement as a potential flaw. A potential defect won't be reported unless its length equals or exceeds minimum flaw length settings. (Flaw detection parameters will be described later.)

LaserLinc offers flaw detection as a standard feature in its processors. Processors are discussed on the last page of the document.

It is important to note that flaw detection occurs simultaneously with diameter, ovality, and any other measurement made by the scanning laser micrometer. Neither operation impacts the other.

Detectable Flaws

Five parameters determine whether scanning-based flaw detection is capable of identifying a flaw: flaw size, flaw shape, flaw length, line speed, and measurement rate.

Flaw Size and Shape

The size of the flaw is simply the product diameter as measured by the laser micrometer. The flaw shape describes how the flaw appears on the product: is the flaw evident around the entire circumference of the product or only over a small portion of the circumference? If the flaw covers the entire circumference of the product, then a single-axis micrometer can detect the flaw because the defect will be visible to the micrometer regardless of product orientation.

Flaw Length, Line Speed, and Measurement Rate

The line speed and measurement rate parameters determine the length of product that passes through the micrometer between measurements. If the length of a flaw is less than the length of product that passes by between measurements, it is possible that such a flaw will go undetected. Below is a general formula for calculating the length of the shortest reliably detectable flaw, based on line speed and measurement rate.

Plug your minimum flaw length and line speed into the following formula to determine the minimum measurement rate for your application:

$$Minimum\_Measurement\_Rate = \frac{feet}{minute} \times \frac{minute}{60\,seconds} \times \frac{12\,inches}{foot} \times \frac{2^{+}}{\text{minimum flaw length } inches}$$

Formula 1: Calculate the minimum measurement rate to detect a flaw of a given length at a given line speed

Note: the 2^{+} in the last factor of the equation is there because with just two samples over the shortest-length defect, it would be possible for the flaw to pass by exactly between those two samples. To ensure that defects of the minimum length are always measured requires more than two samples over the minimum length.

The next formula shows how to calculate the distance between measurements based on a given measurement rate and line speed:

$$Measurements\_per\_Inch = \frac{feet}{minute} \times \frac{minute}{60\,seconds} \times \frac{12\,inches}{foot} \times \frac{1}{measurement\_rate}$$

Formula 2: Calculate the number of measurements per inch

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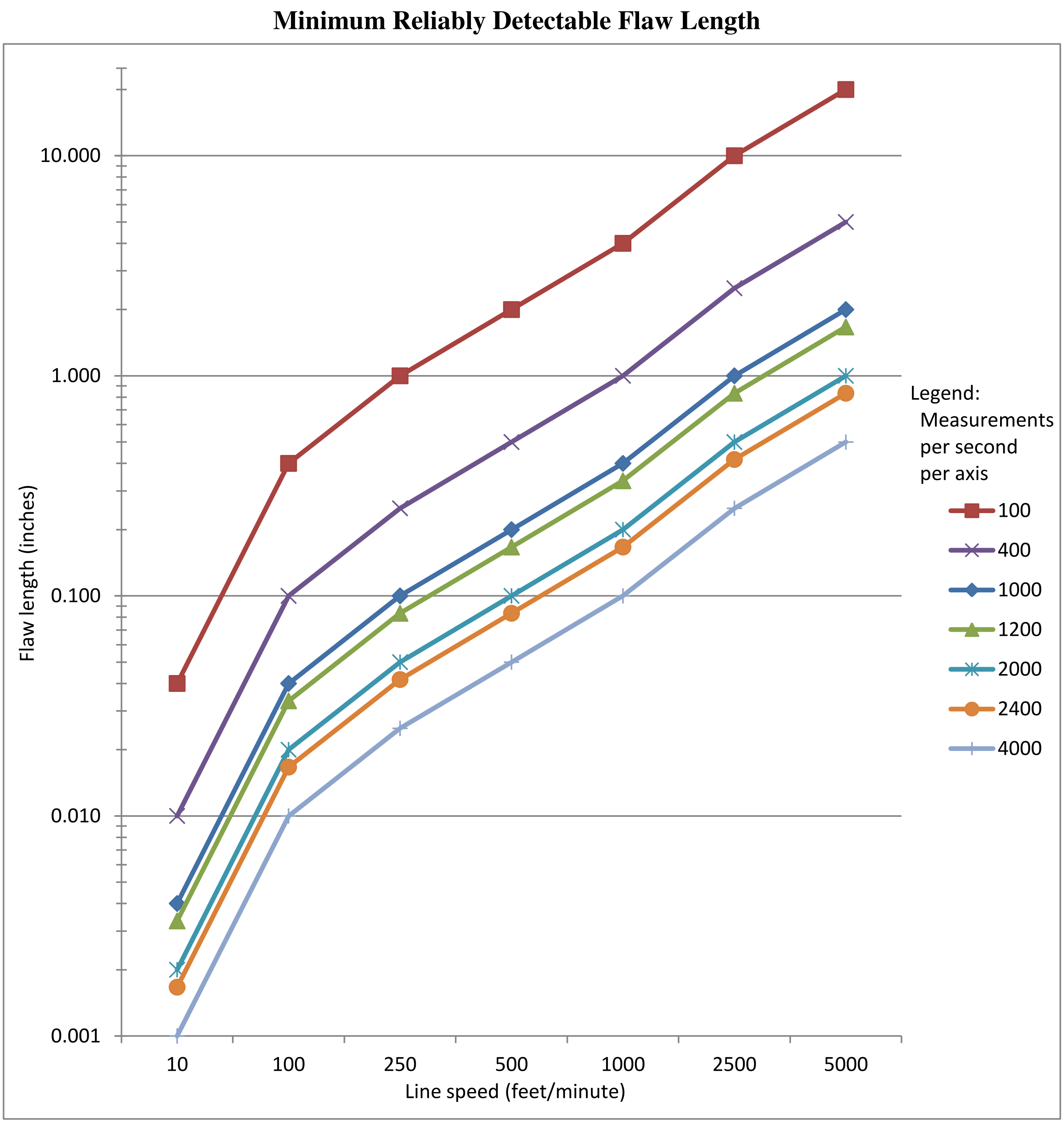
The graph below shows some examples of the minimum detectable flaw length, given a specific line speed and measurement rate. (Note: the y-axis is logarithmic.)



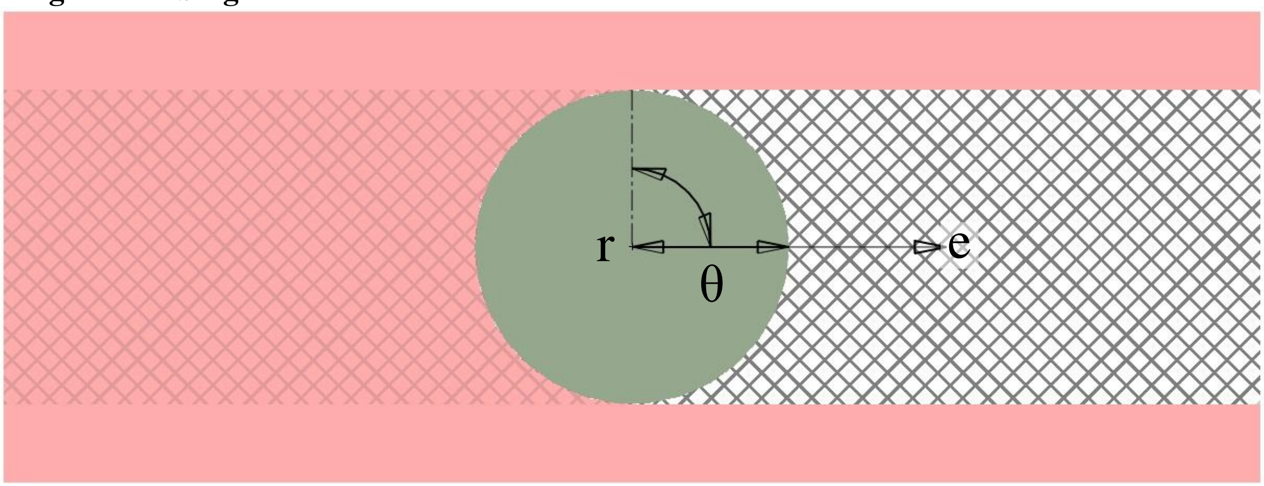
Number of Axes of Inspection

Flaw shape is an important component when determining the requirements of a flaw detection system. If all flaws are exhibited around the entire circumference of the product, then a single-axis device will see them. However, if a flaw is only present in a quadrant or even smaller region of the product's circumference, then that flaw could pass by a single-axis micrometer at an orientation where it is not seen. The same can be said for multi-axis devices.

The diagrams and spreadsheet that follow show the impact of the number of axes of measurement on whether flaws of a particular size and shape are likely to be caught. In the diagrams:

- **r** is the radius of the product being measured
- **θ** is the angle at which a defect is least visible to the micrometer
- **e** represents the largest protrusion that would remain unseen if it occurred at the angle **θ**
  e = **r** • (1 ÷ cos(**θ**) – 1)
- cross-hatching indicates blind spots, areas where the micrometer cannot detect size changes

Diagram for Single-Axis Flaw Detection



With a single-axis micrometer, it is theoretically possible to have an infinitely large defect that remains unseen. From a practical point of view, consider a single-axis micrometer oriented above and looking down at a product emerging from an extruder. Any amount of die drool could hang from the product and remain hidden from the micrometer's view.

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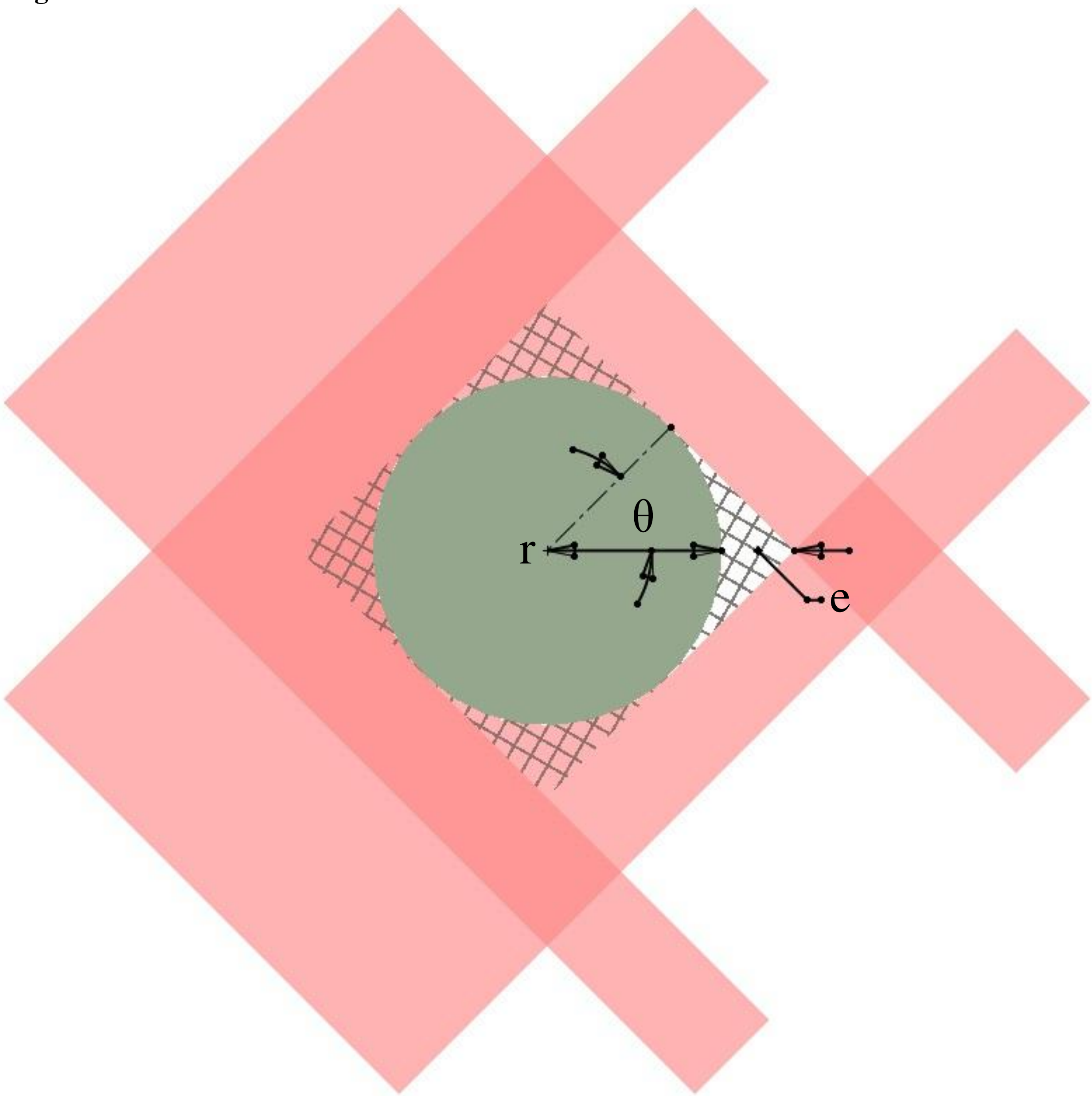
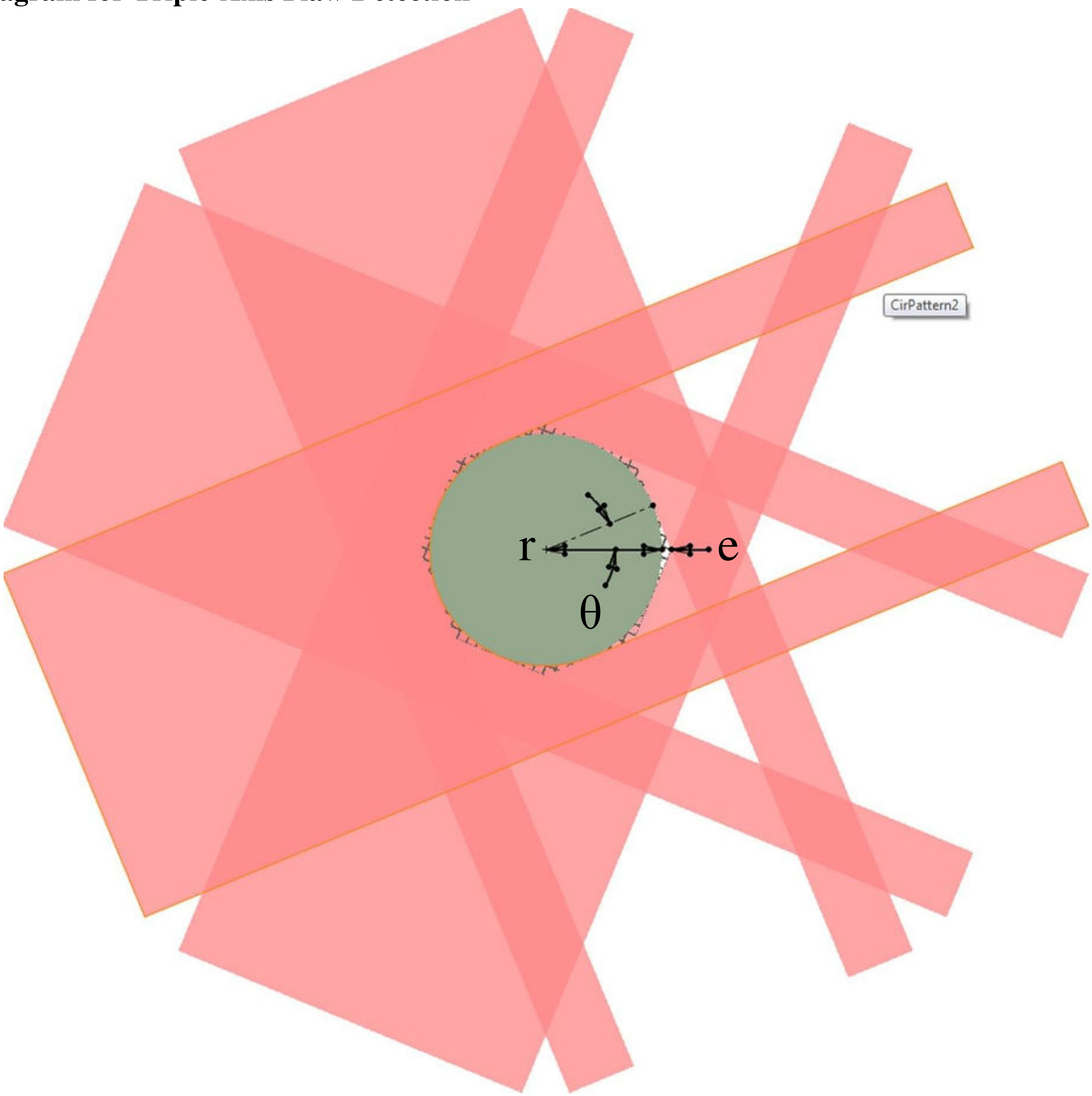
Diagram for Dual-Axis Flaw Detection



With a dual-axis micrometer, blind spots are bounded. Thus, you could say that a dual-axis micrometer provides infinitely better insurance against allowing defects to pass than a single-axis micrometer. With a dual-axis micrometer, as defects grow larger, at some point they will all be detected regardless of flaw shape or orientation on the product.

Diagram for Triple-Axis Flaw Detection



A Triton™ triple-axis micrometer from LaserLinc reduces blind spots by about 268% over a dual-axis micrometer. It is evident from the reduction in the cross-hatched areas in the diagram that a triple-axis micrometer will provide a significant improvement over a dual-axis micrometer in detecting flaws (and also changes in average diameter).

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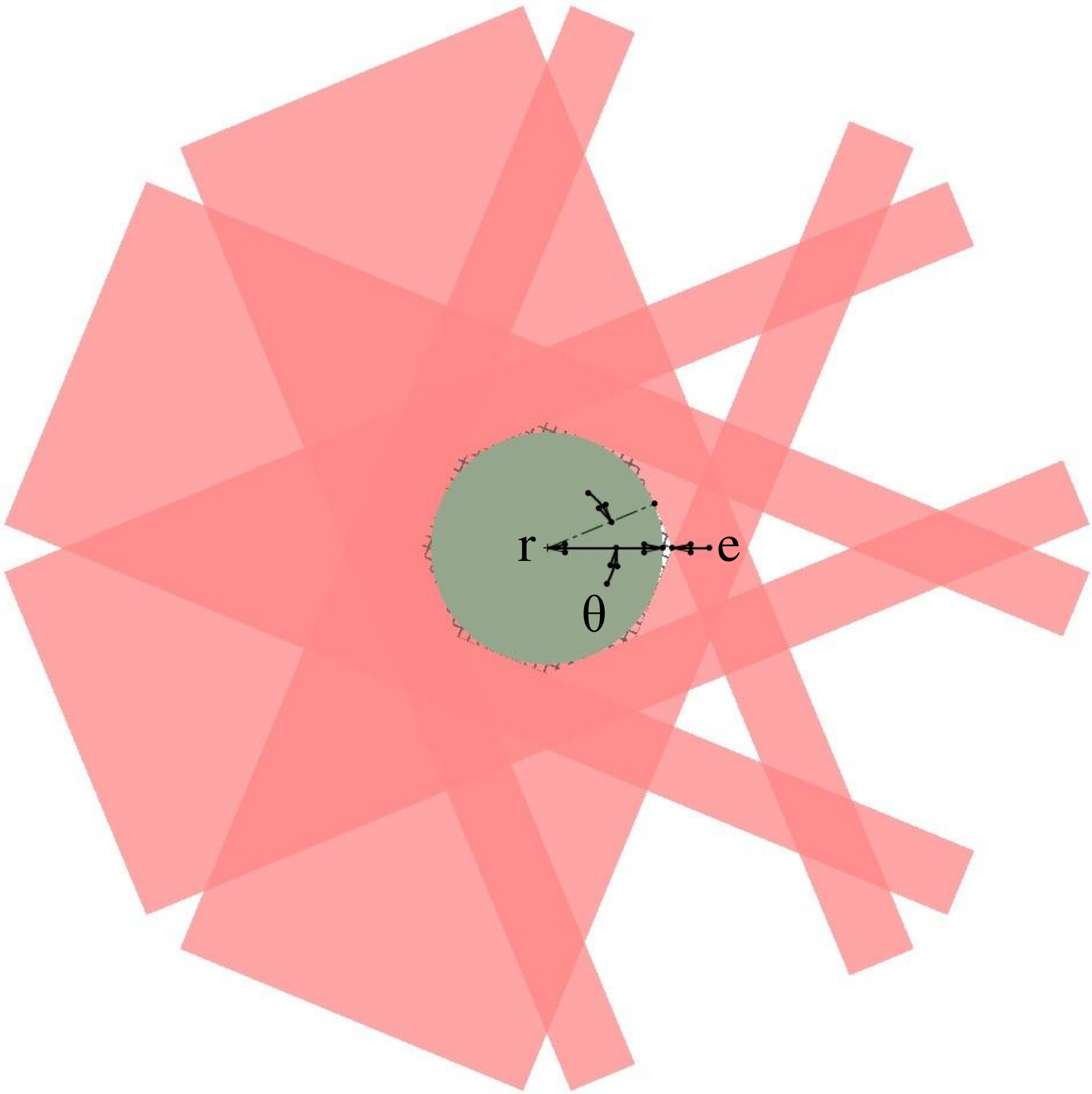
Diagram for 4-Axis Flaw Detection



A four-axis system reduces blind spots by about 188% over a triple-axis micrometer, and by about 503% over a dual-axis micrometer. LaserLinc can supply four co-planar single-axis devices or two dual-axis devices to implement a four-axis system. With two dual-axis devices, there is a very small distance between the two measurement planes; however, the risk of product twist occurring between the two planes is virtually zero.

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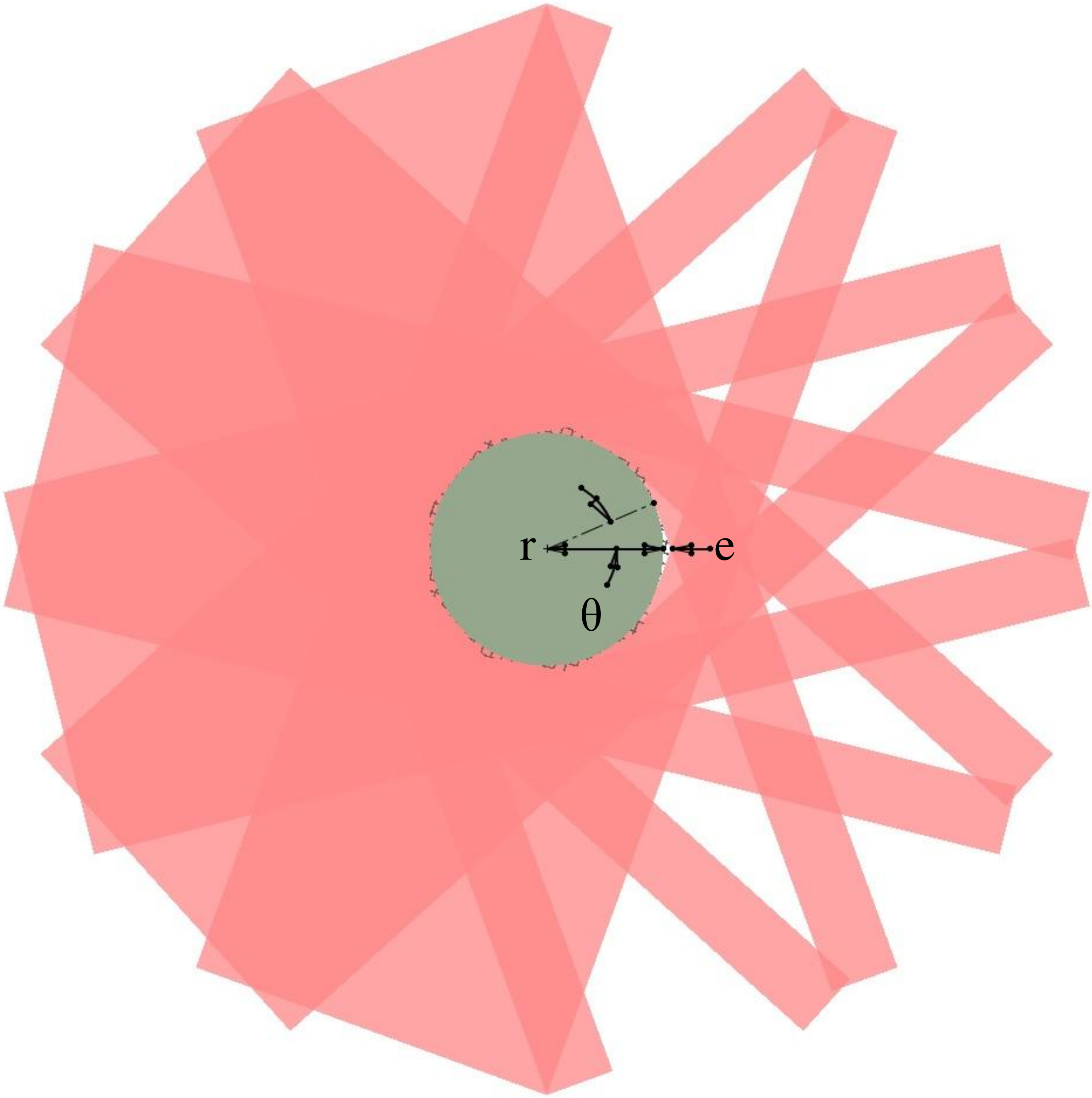
Diagram for 6-Axis Flaw Detection



A six-axis system reduces blind spots by about 234% over a four-axis system, and by about 1174% over a dual-axis micrometer. LaserLinc can supply two Triton™ triple-axis devices mounted such that the measurement planes are offset by a very small distance. The risk of product twist occurring between the two measurement planes is virtually zero.

Blind Spots

Scanning laser micrometers use a shadow-based, through-beam measurement principle. As you can see in the preceding diagrams, there are areas (indicated by cross-hatching) around a round product where size variation can go undetected. The spreadsheet below quantifies these blind spots, for a given product diameter and flaw size.

As discussed earlier in this document, a flaw measurement value must exceed a flaw threshold in order to be flagged as a defect. In the spreadsheet, Minimum Flaw Size is the value used to establish the flaw thresholds.

Nominal Product Diameter		Number of Axes of Inspection	Worst-Case Defect Orientation	Blind Spot Size	Largest Oversize Defect Missed
0.25		1	90	∞	∞
		2	45	0.0518	0.066
		3	30	0.0193	0.031
Minimum		4	22.5	0.0103	0.021
Flaw Size		6	15	0.0044	0.015
0.01		9	10	0.0019	0.012

Worst Case Defect Orientation is the angle at which a defect is least visible to the micrometer. This corresponds to **θ** in the diagrams.

Blind Spot Size corresponds to **e** in the diagrams. A protrusion of this amount could occur on the product without any noticeable change in the micrometer reading, if it occurs at the worst-case orientation and its shape lies inside a blind spot (indicated by cross-hatching in the diagrams).

Largest Oversize Defect Missed is the largest defect that could occur and remain undetected, if oriented at exactly the worst location on the product. (In the diagrams, the worst locations are indicated by cross-hatched areas.) Given the Minimum Flaw Size, it is possible that a defect of this size would not trigger a flaw report.

Note: Contact LaserLinc for a copy of the spreadsheet in electronic format.

Special Case: Circumferential Flaws and Multi-Axis Micrometers

If product orientation is not a factor, i.e. the flaws encircle the product, and since most of LaserLinc's dual-axis micrometers measure the product in each axis in an alternating fashion (X-axis, then Y-axis, then X-axis, then Y-axis, etc.), a dual-axis micrometer can detect circumferential flaws half the length of those detectable by a single-axis micrometer with the same measurement rate. Similarly, a high-speed Triton™ triple-axis micrometer from LaserLinc can detect circumferential flaws a third the length of those detectable by an equivalent speed single-axis micrometer.

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Lump and Neckdown Detection Parameters

Lump and Neckdown detection has six parameters that control what constitutes a flaw: flaw averaging, flaw detection mode, absolute flaw size, relative flaw size, minimum flaw length, and flaw reset length.

Flaw averaging specifies the number of measurements from the micrometer to average together to compute a *flaw measurement value*. Each flaw measurement value is compared to the absolute flaw size and/or relative flaw size parameters to determine whether a flaw may be present.

The system keeps a list of the most recent measurement values from the micrometer. The number of values in the list is specified by the flaw averaging parameter. The average of the values in the list is the flaw measurement value.

Determining a value for flaw averaging depends foremost on the number of measurements made per inch (or other unit of distance). Using the measurement rate of the micrometer and the line speed, you can calculate the number of measurements the system will make on the shortest flaw you are trying to detect. If the result of the calculation is 1 or less than 1, then there is no choice: you must use 1 for flaw averaging. If the result is 10, for example, then you could decide to average up to 9 values to improve the confidence level in the flaw measurement value.

Flaw detection mode has three choices: absolute, relative, or both. Absolute mode establishes fixed limits outside of which a flaw measurement value qualifies as a lump or neckdown. Relative mode establishes floating thresholds based on the previous measurement value plus or minus a constant. Both mode uses the relative *and* absolute flaw thresholds for detecting lumps and neckdowns. The methods available for establishing the absolute and relative thresholds depend on the processor.

Some measurement values may be below a low flaw threshold and some may be above a high flaw threshold. Determining whether a flaw is present is not dependent on whether there are only high flaw measurement values, only low flaw measurement values, or a mix of high and low flaw measurement values. If high *and* low flaw measurement values occur over the length of a flaw, the flaw will be reported as type *both* rather than as only a lump or only a neckdown.

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Minimum flaw length settings, in effect, define a "runs test" for determining whether a flaw has occurred. The minimum flaw length can be specified as a measurement count or in units of time or distance, with the Zero Latency Encoder Input option.

Units	**Minimum Flaw Length Description**
Measurements	The number of flaw measurement values where the flaw measurement value must exceed an absolute or relative flaw size threshold in order to be reported as a flaw.
Time	The amount of time during which the flaw measurement value must exceed an absolute or relative flaw size threshold in order to be reported as a flaw.
Distance	The distance over which the flaw measurement value must exceed an absolute or relative flaw size threshold in order to be reported as a flaw.

The minimum flaw length settings allow for detecting flaws even when they are not one continuous lump or neckdown. For example, with minimum flaw length specified as 5 out of 10 measurements, if any five out of the last ten flaw measurement values qualify as a lump or a neckdown, the system will report a flaw. Whether all five are in a row or whether there is an acceptable flaw measurement value in between each pair of bad values would not matter.

Flaw reset length specifies how the system recognizes the end of a flaw.

Units	**Minimum Flaw Length Description**
Measurements	The end of a flaw is recognized after the specified number of consecutive flaw measurements is made where all flaw measurement values lay within the flaw thresholds.
Time	The end of a flaw is recognized after the specified amount of time has elapsed during which all flaw measurement values remained within the flaw thresholds.
Distance	The end of a flaw is recognized after the specified distance has elapsed during which all flaw measurement values lay within the flaw thresholds.

Flaw reset length is useful for controlling whether the system reports multiple flaws spaced closely together as multiple distinct flaws or as one longer flaw. Once the minimum flaw length requirement has been met, the system will expect to see the flaw measurement values inside of the flaw thresholds for an entire flaw reset length period before the current flaw is reported. Then the system will begin looking for the next flaw.

In short, minimum flaw length defines how long a flaw must be and flaw reset length does two things: it specifies how long to wait after detecting a flaw to guarantee that the entire flaw has passed and it defines when to reset the flaw detection process and start looking for the next flaw.

Processor Platform

Flaw detection is included **at no charge** in Total Vu™ software and the SmartLinc™ processor.

With the SmartLinc processor, flaw status and flaw count information may be exported via industrial communications such as EtherNet/IP, Ethernet User Datagram Protocol (UDP), or ASCII.

With Total Vu software, a flaw report is available that can be printed, saved to a comma separated values (CSV) file, or both. With the Excel® reporting option, the flaw report can be added to any Excel report template. With the digital I/O option, an external device such as a light, buzzer, cutter, or paint sprayer can be activated when a flaw is detected.

Total Vu Software - The Flaw Report

Each line of the flaw report contains the date, time, distance into the run (if the encoder option is enabled), the type of flaw, the flaw measurement value that captured the largest excursion of the flaw from a flaw threshold, and the length of the flaw (in the same units as were selected for the minimum flaw length). The fields are comma separated for easy import into most spreadsheet, database, and statistical software. The report can be saved to disk or sent directly to a printer.

(Note: to make the example report below more readable, spaces have been added and commas removed.)

```
Date          Time      Distance   Type        Worst    Length
18-Jun-2013   10:37:34  16080.2    Neck Down   0.2119   180
18-Jun-2013   10:37:46  17314.1    Neck Down   0.2141   418
18-Jun-2013   10:38:13  19993.6    Lump        0.2697   479
18-Jun-2013   10:39:18  26541.0    Lump        0.2516   113
18-Jun-2013   10:39:28  27544.4    Neck Down   0.1723   214
18-Jun-2013   10:39:36  28429.8    Neck Down   0.1744   272
18-Jun-2013   10:39:58  30577.8    Lump        0.2661   109
18-Jun-2013   10:39:59  30730.9    Neck Down   0.1815   168
18-Jun-2013   10:40:09  31698.7    Neck Down   0.1735   145
18-Jun-2013   10:40:10  31861.0    Lump        0.2660   109
18-Jun-2013   10:40:14  32240.0    Lump        0.2838   131
18-Jun-2013   10:40:41  34935.3    Lump        0.2569   101
18-Jun-2013   10:43:05  47432.5    Both        0.2704   745
```

With an encoder connected to the system, the distance at the beginning of each flaw is also recorded.

Contact Us

laserlinc

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