INTRODUCTION

As tire specifications become more stringent, tire manufacturers require their suppliers to develop faster, more sophisticated and more accurate measurement and inspection devices for both on and off line applications. The basic need is for dependable devices that inspect tires with better throughput, higher sampling rates and longer stand-off distances without sacrificing accuracy. Reducing overall system cost is another recognized requirement. Manual re-inspection of false rejects must also be minimized.

Thousands of laser based sensors are in use today in tire manufacturing operations, both for in-process monitoring and final tire inspection. Significant recent developments offer major enhancements to implementing laser sensors in tire operations, including:

- **High speed digital** data output from the sensor simplifies implementation, eliminates electrical noise interference on analog lines and improves data precision.

- **Smart Sensors with software inside** – with application specific software, such as radial runout calculations, operating inside the sensor to simplify implementation, eliminate the cost and maintenance of external computers or PLCs, and improve system reliability.
Both of these enhancements are available to improve system performance and reduce cost in all in-process and final inspection operations for tire manufacturers.

**LASER SENSOR ADVANTAGES**

For both in-process and final inspection applications, non-contact laser measurement sensors have proven superior to traditional contact/mechanical followers or even older capacitive sensors.

Capacitance sensors, although low in acquisition cost, have a number of disadvantages. They have small standoff and must be located close to and perpendicular to the measured surface. Incorrectly positioned tires will destroy the sensors. Capacitance sensors require complex, multiple axis positioning mechanisms, and need frequent recalibration due to sensitivity to material property changes. They do not operate reliably on higher silica rubber. Capacitance sensors measure over a large footprint on the surface, and do not produce reliable data over grooves, lettering and bar codes for final inspection, requiring positioning over a clear path on sidewalls.

Contact sensors, such as LVDTs (linear variable differential transformers) have similar disadvantages. Contact pressure will deform the rubber, resulting in erroneous data. In-process measurements such as extrusion profiling are impractical due to the hot, gummy rubber surface. For final inspection, these sensors also need a clean path on the tire to measure consistently. The tire lettering or embossments will destroy the touch probes as the tire rotates at 60 revolutions per minute (rpm). At lower speeds, any lettering, grooves, sipes, pin vents or embossments on the tire also severely reduce repeatability due to unwanted contact bounce.

High performance non-contact laser triangulation sensors have been successful in meeting the measurement challenges of tire manufacturers for decades. Non-contact operation measures rubber without deformation errors. Laser sensors have large standoffs (typically several hundred mm or more, depending on specific sensor type), larger measurement range, and obtain reliable data even when not perpendicular to the surface, which simplifies sensor mounting and positioning and eliminates sensor crashes. Properly designed laser sensors do not require recalibration, are insensitive to material property changes and are not affected by changes in surface condition, such as color, finish or bead lubricant.

Point triangulation sensors provide extremely high data rates (16 to 32 kHz) and resolution down to 25 microns. Coupled with very small laser spot size, these sensors
provide accurate profiles of tires at high speed. For final tire inspection, accurate profile
data can be analyzed in software to eliminate effects of lettering, bar codes, sipes, pin
vents or grooves, without also masking small but important grooves or bulges on the
surface. These sensors have been described as providing a 10X improvement in
measurement precision over contact methods.

Recent development of “smart” sensors and higher speed digital data output has
significantly improved sensor capability and reduces total cost of system implementation.

LASER MEASUREMENT PRINCIPLES

Two types of laser measurement sensors are commonly used to measure tires at various
points in the manufacturing process. The oldest is point triangulation, which is the basis
of the vast majority of laser sensors used today (totaling several thousand units). The
second method is laser line sensing, used in tire manufacturing for about 2 years, in
limited numbers.

Point Triangulation Method

The laser triangulation principle, in its simplest form, is illustrated in Figure 1. A low
powered, usually visible, laser is projected to form a spot at the surface to be measured.
At an angle to the laser beam, an imaging lens forms an image or picture of the laser spot.
As the surface moves towards or away from the sensor, the position of this imaged spot
shifts laterally at the image plane. An electronic position sensing detector (usually an
analog device known a Position Sensitive Detector or PSD) placed at the image plane
detects the position of the spot, and electronics calculate the distance from the sensor to
the surface by calculating the triangle formed.

![Figure 1 Triangulation Principle](image)
The point triangulation sensor measures data at a single point, effectively as a non-contact LVDT, with a very small probe size, typically 0.1 to 0.3 mm diameter. These sensors also have stand-off distance (from the front if the sensor to the surface being measured) of 50 to 500mm, providing better environmental cooling and essentially eliminating “crashes” or physical damage.

Laser Line Method

The principle of laser line sensing (Figure 2) is quite similar to point triangulation. The major difference is that the laser beam is optically expanded in one dimension to create a line of laser light on the surface to be measured. The detector used is a 2D digital array or camera. The output of the 2D camera is analyzed electronically, with many points along the line calculated in the triangulation equations.

![Figure 2 Laser Line Principle](image)

The laser line sensor measures at a number of points along the laser line in each camera image or frame.

Point Sensor vs. Line Sensor Performance

Point triangulation based sensing has been very successful in tire measurement since this offers extremely high data rates (16 to 32 kHz), both analog and digital outputs for simple interfacing and resolution as low as 25 microns. Properly designed PSD based sensors also automatically compensate at high speed for surface reflectivity changes, insuring accurate data is obtained from all surface conditions, and experience has shown that surface conditions of rubber can vary dramatically and rapidly during a production run.
Laser line sensors, which take data over multiple points on the surface, are slower in data rate, typically 10 to 60 frames per second for each line of data. Resolution is typically lower than point sensors. Also, light level control for line sensors is an issue since the camera takes data over the full line width for each exposure and must assume the surface is reasonably uniform over the entire line to obtain reliable data.

Selection of the best sensor type for a given application depends on the performance required to suit specific needs. An important factor to consider is the data density required, directly related to the data rate or frame rate of the sensor.

As an example, consider the application sidewall bulge and depression measurement at final inspection. Very high density data is required to properly detect bulges and dents, since the analysis software must first remove or filter out all points which relate to lettering, bar codes and other acceptable variations in the surface. For a tire rotating at 60 rpm, the point sensor provides 16,000 to 32,000 data points per revolution, far greater than a line sensor can provide. The bulge can be anywhere from 0.3 mm to 3.0 mm high and 5.0 mm to 7.0 mm wide. PSD-based laser sensors have the ability to detect a bulge and other deformities quickly on a tire rotating at 60 rpm and measure bulge accurately to better than ±0.025 mm. Bulge heights of significance have been spaced around 0.3 mm. Customers are now asking to restrict heights to 0.2 mm since many bulges are not cord related but are air blisters. Multiple-track point laser measurements provide full-tire coverage and allow effective analysis on sidewalls with complex letter and image patterns.

Cost factors must also be considered. Complete bead to bead final inspection may be feasible, but not practical. Today, laser line sensors have significantly higher purchase cost than point sensors. Another cost factor, impacting total implementation cost is related to laser safety classification. Today’s point sensors used in tire manufacturing are classified 3R, maintaining very simple requirements to comply with laser safety regulations. Many line sensors are classified 3B, and use 30 to 100 mW laser diodes, having more complex requirements for safe implementation.

Laser Safety requirements have always been an important aspect while selecting sensors. Recently the IEC (International Electronics Commission) a worldwide organization and FDA have reclassified lasers as Class 1, Class 2, Class 3R, Class 3B and Class 4. The IEC standard 60825-1, Class 3R allows a maximum laser power of 5mW and assumes all Class 2 regulations as long as the wavelength is between 400-700nm. This eliminates the need for a Laser Safety Officer and only requires basic training for all operators and maintenance personnel.
PERFORMANCE TEST – POINT SENSOR

Recently, a performance test was carried out mounting a point triangulation sensor on a 24 segment tire building drum, measuring radial runout (Figure 3).

Figure 3 Tire Building Drum

A small magnet was placed on one segment and the drum rotated. Figure 4 shows the runout as measured by the sensor, with the magnet clearly visible.
Two layers of rubber were placed on the drum, and the rotation monitored (Figure 4).

The small waves show the out of roundness of the tire due to the 24 segments of the drum. One segment shows the effect of the magnet over a width of 1mm, clearly visible from the accurate sensor data. One segment is not tied well and can move around, which remains visible while building up the tire.

NEW DEVELOPMENTS IN SENSOR INTERFACING
High sensor measurement data rate is required to inspect tires reliably without limiting production rates. But there is more involved than just the sensors ability to take data at high speed – the sensor must also communicate its measurement data to a PC or other device at high speed to be effectively implemented. Standard digital interfaces, such as RS-232 and RS-422 have speed limitations when used with high speed triangulation sensors. As a result, most point sensor implementations have communicated data by analog methods, which can transmit data at the full bandwidth of the sensor. However, analog transmission can pick up unwanted electrical noise from the plant environment, and requires that the receiving device be equipped with an analog to digital converter, which adds cost.

Some systems have been implemented with a non-standard digital communication protocol, which, while effective, adds interfacing cost to the user as well as the need to maintain a non-standard interface.

To eliminate the issues of electrical noise pickup as well as the cost of A/D conversion in the receiving device, a high speed streaming RS-422 capability has been added to point triangulation sensors, with capability to transmit measurement data at 460 kbps. This allows sensor data to be transmitted *digitally* at the maximum sensor data rate. The implementation allows the user to select operation with traditional analog or digital outputs as well as the high speed streaming RS-422 option.

With high speed streaming data, output from the sensor is essentially in real time. This allows measurement sensor data to be combined with information from other sensors, such as encoders monitoring tire rotational position during the inspection cycle. Examples of implementation include radial runout inspection with capability of measuring the position of the maximum radius on the tire. Another capability is being able to adapt analysis to the actual speed of rotation, either in final inspection or during the grinding operation, without requiring close rotational speed control.

**SMART SENSORS WITH APPLICATIONS INSIDE**

A new development, smart sensors support customized sensor algorithms running in the sensor, eliminating the need for PLC and PC controllers.

Most sensors used in tire monitoring applications have been “smart” sensors, with the software and hardware for controlling sensor operation running inside the sensor enclosure. These software functions include linearization, conversion of measurement
data to engineering units (digital output), automatic gain control to insure data is accurate even when the object surface reflectivity varies rapidly, low pass filtering, and analog to digital conversion in some cases. Sensor operating parameters for specific types of applications are also stored inside the sensor.

Recent developments in smart sensor technology have expanded the processing capacity inside the sensor to allow additional processing ability (generated by the sensor manufacturer, the systems integrator or the end user) to reside in the sensor head, along with sensor operating software. The technology incorporates a powerful 32-bit RISC processor and large amount of memory (both RAM and non-volatile), giving the sensor the capability to host large and complex application programs (Figure 5).

![Figure 5 Smart Sensor with RRO Application Software Inside](image)

The new smart sensor technology (with application software inside) integrates sensor data collection and control software functions within the sensor head for high efficiency and reduced system costs by eliminating the need for an external controller (PC, PLC or other device). The technology also simplifies software routine programming and sensor control.

The smart sensor also eliminates concerns about needs for high speed data transmission capability from the sensor, since data analysis is done in the sensor and only simple results of the analysis are transmitted.
The configuration improves robustness by eliminating the need for external processing devices, and enhances security for integrators installing proprietary processing algorithms. It can be used in a variety of tire processing applications such as thickness profile, splice width, radial runout and sidewall integrity monitoring.

The smart sensor, with application specific software running inside the sensor reduces cost and complexity of implementing new inspection stations. It also makes retrofitting of older systems (replacing contact or capacitance sensor based systems) more attractive, since the retrofit consists essentially of mounting the laser sensors without need for added computers and interfacing.

*Implementation example – radial runout of finished tires*

All new tires have grooves, sipes and pin vents. These features produce measurement values that deviate by very large amounts (negative for grooves and sipes, positive for pin vents) from those that originate on the tread surface. These deviating measurement values must be eliminated from the data stream before roundness analysis is applied.

The only hardware to implement this application is to mount a suitable encoder to monitor the tire rotation, with its output sent to the sensor connector. Pulses from the encoder are used to trigger the sensor readings at regular intervals as the tire rotates.

The raw data, before processing, from a typical new tire will look like Figure 6.
The Y axis is the sensor output, converted to engineering units. The two big grooves are tread gaps, at a height difference of about 8 mm. There are also some smaller dips in the signal, caused by sipes. Two values that rise above the general tread level are caused by pin vents.

The two solid horizontal lines show how the software has calculated the interval where the signal is "in band", i.e. where the expected tread surface is located, about 0.6 mm high.

Software running inside the sensor head carries out a histogram analysis, binning and stripping of unwanted data, and then linearly interpolates data across the tread grooves. The result is the data plot of Figure 7, representing the true or effective radial data for the tire (with an expanded Y axis scale).
CONCLUSIONS

For all in-process and finished product applications, laser sensors are used in the rubber and tire industry to enhance competitiveness by improving productivity. The basic benefits of using laser sensors for quality control include: increasing yield and productivity, increasing quality by providing 100 % product inspection, reducing scrap production and rejects, and in-process inspection to detect and correct trends quickly before production of scrap.

- New developments in laser based measuring systems can now provide high speed digital data communications, eliminating the effects of errors from electrical noise and eliminating the need for A/D converters.

- New smart sensor developments allow application specific analysis software to run inside the sensor, simplifying operation, improving reliability and reducing cost by eliminating the need for external signal processing hardware.

Figure 7 Actual Surface Radial Runout Profile