The use of noncontact laser gauging systems for online measurement

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Introduction

The term “laser” is an acronym for light amplification by stimulated emission of radiation. Stimulated light emission occurs when an atom or molecule that is holding excess energy is stimulated to emit that energy as light. In 1960 Theodore Maiman, of Hughes Research Laboratories, invented the first laser capable of emitting a coherent light (Maiman, 1960). However, it was not until 1973 that H. Petrohilos and P. Diles received a patent for their development of the first noncontact laser gauging system (NCLGS). Technical developments in this field have resulted in measurement devices that were unimaginable only a few years ago. These developments occurred primarily in three areas. The first involved the replacement of analog peak detection circuitry by digital signal processing (DSP). This resulted in improvements in edge detection and in minimizing the influence of contaminants on measured products. It also allowed the use of far less expensive optical components. Through use of appropriate logic circuitry, NCLGSs now could also be used to measure shiny surfaces and opaque objects. Automated four-axis systems have even been developed which are able to capture complex 3D surface data. Second, increases in scanning speeds up to 2,200 scans/sec., and in scanning velocities up to 5,600 inches/sec. enabled a much higher number of individual measurements to be made in a given time than earlier units. Third, reductions in package size allowed manufacture of ever-more compact units. Portable units that can be used at multiple and remote sites can now be produced.

Although NCLGSs utilize a relatively new technology, they have become an accepted tool for online measurement of manufactured products. Increased awareness of potential savings through the use of this technology, and increased pressure on manufacturers to produce quality products, have driven the development of these systems (Marseli, 1999). The purpose of this paper is to introduce the reader to the basic operational principles of an NCLGS and to review the primary benefits and potential problems associated with these systems.
Techniques

There are typically two components in an NCLGS: a scanner consisting of a transmitter and a receiver, and a processor. The transmitter generates a collimated light source by bouncing a laser beam off a spinning mirror, through a lens, and along a vertical plane. Current systems utilize HeNe gas tubes and laser diodes, both visible and infra-red, with power outputs from 0.8 to 5Mw. Scanning speeds will range from 100 to 2,200 scans per second. Scan velocity, the movement of the laser beam sweeping across the collimating lens, can range from 2,200 to 5,600 inches per second, depending on scanner type. The object to be measured is placed in the measurement area of the gage, consisting of a vertical plane where the pass line and the scan centerline intersect. The pass line is the vertical center of the scanning beam. The scan centerline is the horizontal center of the scanning beam (Figure 1). The presence of the object in the measurement area divides the collimated light source from the transmitter into three segments:

1. leading light segment;
2. shadow segment; and
3. trailing light segment (Figure 2).

The divided segments of the light source pass through the scan window and lens of the receiver, where they are collected and focused onto a photocell. Electronic circuitry converts the received light into an electrical signal with peaks and valleys proportional to the sizes of the light and shadow segments respectively. The digital processor is able to interpret the portion of the signal corresponding to the shadow segment to determine the size of the measured object. The inspection process described is known as “scanning”. The smallest size a scanning laser can measure is determined by the spot size, the actual size of the scanning laser beam as it crosses a measured part.

Making use of the leading light, shadow, and trailing segments, the NCLG measures products using diameter, edge, position, or custom measurement modes. Diameter measurement is used to measure the diameter of a single object placed in the measurement area (Figure 3). Position measurement is used to measure the distance between the center of the measurement area and the center of the shadow of the object being measured (Figure 4). Edge measurement is used to measure the distance from a reference surface to the edge of the object to be measured (Figure 5). The custom mode is used to measure complex or multiple objects that cannot be measured using diameter, edge, or position measurement modes (Figure 6).

Figure 2 Shadow terminology

Figure 3 Diameter measurement
Benefits of using NCLGSs

NCLGSs offer a number of clear advantages over just about every other type of diameter gauging system. NCLGSs are able to continuously monitor a manufacturing process, determine the current product dimensions, and alert the operator should the product deviate from an acceptable range (Plate 1). With this online inspection capability, the NCLGS provides a means for immediate operator feedback, allowing for timely adjustments to the manufacturing process. Data can also be collected to perform statistical analysis and construct process control charts. The result should be a significant reduction in scrap.

NCLGSs also enable us to measure extremely thin-walled parts or soft materials. Contact pressure from a mechanical gauge, or from an electronic gauge head can distort or compress the material, resulting in an inaccurate measurement. The ability to accurately determine the diameter of an object without contacting it allows measurement of such parts without loss of accuracy. Parts measured can be made of any material, from steel to rubber.

NCLGSs provide excellent resolution, enabling them to be used to detect very small dimensional changes that otherwise would not be detectable using a caliper or co-ordinate measuring machine. This is important when determining the ovality of a part. Ovality is defined as the difference between the minimum and the maximum dimension on a single plane.

Issues for concern

Despite these advantages, there are a variety of problems associated with the use of NCLGSs for diameter measurement. Below are six potential problems.

Plate 1 A laser gauging system used to monitor a wire drawing process
First, the part must be positioned perpendicular to the measurement beam to avoid occurrence of a cosine error. A cosine error occurs when the part is positioned so that it is not perpendicular to the beam and the resulting shadow measured by the receiver is larger than the part being measured. Figure 7 illustrates a part with a 1mm diameter presented to the beam at 95°. Figure 8 depicts the cosine error caused by this misalignment of the part. The 1mm diameter of the part is read as 1.003800.

Second, cleanliness of the item being measured is important. Any foreign substance on the measured object will displace the light source, and the result will be an incorrect measurement. Fortunately, recent improvements in circuitry logic have reduced the seriousness of this problem.

The third problem deals with the positioning of the part within the laser beam. In general, an object placed anywhere in the scanning laser beam can be measured as long as it creates a shadow. However, to obtain maximum accuracy, measurements should be taken as close as possible to the intersection of the pass line and the scan centerline. This is the point at which the manufacturer’s accuracy specifications apply and where performance is consistent with initial factory calibration and alignment. As an object moves within the measurement area away from the scan centerline, errors will become more prominent, depending on the direction and magnitude of this motion. In general, measurements are less affected by horizontal motion along the scan centerline than by vertical motion along the pass line. As the object is moved along the horizontal scan centerline, there is less effect on the error because the object remains within the collimated light source. As the object is moved vertically along the pass line, the error is larger because the object approaches the edges of the collimated light source. The same effect would also be observed if one attempted to measure an object that was too large for the particular gauge. In this case, a larger NCLGS would need to be selected.

The fourth potential problem deals with the degree of error traceable to calibration issues. This is a particularly important issue in the use of NCLGSs because of their superior accuracy and resolution compared to most conventional dimensional measurement equipment. For example, the resolution for NCLGS can be as little as 0.000001in. In comparison, the resolution of co-ordinate measuring systems will be approximately 0.00004in.

NCLGS processors are high-precision comparators. In effect, they determine the measurement of an object by comparing the shadow segment of the measured object to the shadow segment of a calibration gauge, or master. Before an NCLGS is sold it is calibrated by the manufacturer using NIST or comparable traceable standards. The end user then should master the NCLGS to a gauge pin that is as close as possible to the size of the object to be measured. This will result in the highest accuracy measurements.

In addition to the need to master using an appropriate size gauge, there is a need to measure the calibration gauge in the same portion of the light source in which the manufactured product will be measured. Variations in temperature in the measurement environment can also result in a significant degree of error and the need for frequent calibration. The importance of maintaining a controlled environment is directly related to the required measurement.
accuracy. For example, a shop floor environment with significant fluctuations in temperature would not be appropriate for measurements requiring accuracy of $\pm 0.00001\text{in}$. The end user should be careful to enforce a calibration policy appropriate to the specific environment and required accuracy.

Fifth, for optimal accuracy, scanners need to warm up before performing measurements. An NCLGS that is used to make a very accurate measurement needs to be operating all the time to maintain stability.

The sixth problem relates to the issue of measurement uncertainty. Measurement uncertainty is defined as the interval in which can be found the unknown difference between the true value of the feature measured and the result of the measurement. Common practice recommends that the measuring instrument should be ten times as accurate as the manufacturing tolerance for the object to be measured. This is done to limit the amount of instrument error that can creep into the measurement (Busch, 1989). For example, an instrument with an accuracy of $\pm 0.0001\text{in}$ should be used to measure a product manufactured to a tolerance of $\pm 0.001\text{in}$. Using NCLGS with a resolution of $0.000001\text{in}$ would imply a manufacturing tolerance of $\pm 0.00001\text{in}$. However, it would be impractical for the customer to expect the manufacturer to hold to such a tolerance using an NCLGS because calibration gauges are only available to an accuracy of five places ($0.00001\text{in}$). Use of the $10:1$ ratio is no longer valid given the increased resolution and accuracy capability of NCLGS. It is imperative, therefore, that the supplier and customer resolve issues pertaining to uncertainty.

A technology for today

The number of companies using laser measurement technology is growing at a fast pace. Dimensional inspection traditionally has been performed using contact tools such as calipers, micrometers, or, on a larger scale, co-ordinate-measuring machines. Today’s measurement requirements for smaller components, tighter tolerances, and shorter inspection times, increase the need for precision-measurement tools with noncontact capability (Kennedy, 1998). The increased emphasis on improving manufacturing quality and on reducing manufacturing costs have caused the widespread increase in the use of NCLGSs. In recognition of this trend, in 1998, the American National Standards Institute (ANSI) published a new standard that addresses many issues related to laser measurement (ANSI, 1998).

Manufacturing and quality professionals need to recognize the importance of NCLGS technology and explore the benefits and potential problems associated with its use. Only then can they determine whether they will enhance their company’s bottom line.

References


