Laser Tracker

by Bob Bridges, Ph.D.

Many industries, including the automotive and aerospace industries, must precisely measure the three-dimensional features of large objects. An increasingly popular way to do this is with the laser tracker, a device first introduced in the late 1980s. As its name suggests, the laser tracker measures 3D coordinates by tracking a laser beam to a retro-reflective target held in contact with the object of interest.

Some laser trackers can measure object features up close and as far away as 60 meters. Some have typical single point accuracy of about 0.001″ (0.025mm) at distances to several metres. Trackers collect coordinate data at high speed and require just one operator. They offer improved methods of coordinate measurement and make entirely new manufacturing methods possible.

COMPETING COORDINATE MEASURING INSTRUMENTS

Today, many instruments can measure coordinates. Each is best suited for certain applications. Traditional fixed coordinate measuring machines carry out repeated measurements rapidly and accurately but are immobile, limited in measurement range, and expensive for large applications. They are most popular for inspecting small to mediumsized (under one metre) production components where speed and accuracy are important.

For medium to large parts, portable CMMs are preferred. Until the advent of laser trackers, portable coordinate measurement was done mostly with theodolites, total stations (theodolites equipped with electronic distance measurement), articulated-arm CMMs and photogrammetry systems. Due to their high accuracy, high speed, and ease of use, laser trackers have replaced many of these earlier systems.

HOW LASER TRACKERS WORK

The operation of a laser tracker is easy to understand: It measures two angles and a distance. The tracker sends a laser beam to a retro-reflective target held against the object to be measured. Light reflected off the target retraces its path, re-entering the tracker at the same position it left.

Retro-reflective targets vary, but the most popular is the spherically mounted retro-reflector (SMR). As light re-enters the tracker, some of it goes to a distance meter that measures the distance from the tracker to the SMR. The distance meter may be either of two types, interferometer or absolute distance meter (ADM).

A laser tracker contains two angular encoders. These devices measure the angular orientation of the tracker's two mechanical axes: the azimuth axis and the elevation (or zenith) axis. The angles from the encoders and the distance from the distance meter are sufficient to precisely locate the centre of the SMR. Since the centre of the SMR is always at a fixed offset distance with respect to any surface being measured, the coordinates of surfaces or points measured with the SMR are easily obtained.

Distance measurement, an important function of the laser tracker, can be either incremental or absolute. Incremental distance measurement is made with an interferometer and a frequency-stabilised, helium-neon laser.

The laser light splits into two beams. One travels directly into the interferometer. The other beam travels out of the tracker, reflects off the SMR and, on the return path, passes into the interferometer. Inside the interferometer, the two beams of light interfere, resulting in a cyclic change each time the SMR moves closer to or farther from the tracker by a distance equal to one quarter of the light's wavelength (~0.0158 micron). Electronic circuitry counts the cyclic changes (known as "fringe counts") to determine the distance travelled.

In a typical measurement sequence, the operator places the SMR in the tracker's home position and resets the interferometer to the known (home) distance. As the operator moves the SMR to the desired location, the laser tracks along, remaining fixed to the centre of the SMR. This procedure works well as long as the beam from the tracker to the SMR isn't broken by an obstruction in the beam path. If the beam is broken, however, the number of counts is no longer valid and the distance isn't known. When this happens, the tracker signals that an error has occurred. The operator must then return the SMR to a reference point, such as the tracker's home position.

Absolute distance measurement capability has been around for a long time. Within the last ten years, however, ADM systems have undergone dramatic improvement, offering accuracy comparable to interferometers. The advantage of ADM measurement over incremental distance measurement is the ability simply to point the beam at the target and shoot. The ADM system measures the distance to the target automatically, even if the beam has previously been broken. In a tracker with ADM, infrared light from a semiconductor laser reflects off the SMR and re-enters the tracker, where it's converted into an electrical signal. Electronic circuitry analyses the signal to determine its time of flight, multiplying this value by the speed of light in air to determine the distance from the tracker to the SMR.

Absolute distance meters first appeared in laser trackers in the mid-1990s. At that time, ADM units measured too slowly to permit scanning of surfaces. Because of this, all early laser trackers contained either an interferometer alone or an interferometer and an ADM. Today some absolute distance meters have been made fast enough to permit high speed scanning with negligible loss in accuracy. Hence some modern trackers contain only an ADM with no interferometer.

Another tracker function is beam steering and control. One type of tracker launches the laser beam directly from its rotating structure. Another type of tracker reflects a laser beam off a rotating mirror. In either case the tracker points the laser beam in the desired direction by rotating the mechanical axes. In many applications, the tracker keeps the beam centred on a rapidly moving SMR. It accomplishes this by splitting off part of the returning laser beam to a position-sensing detector (PSD). If the laser beam strikes the SMR off centre, the split-off beam also strikes the PSD off center, creating an error signal. This signal controls the mechanical axes' rotation to keep the beam centred on the SMR.

MEASURING COORDINATES WITH THE TRACKER

Trackers collect three-dimensional coordinate data, which can be "fit" by software to geometrical entities such as points, planes, spheres or cylinders. Usually, the data is displayed within a local coordinate system tied to an object's features. A flat surface on the object, for example, may represent the x-y plane. Alternatively, the local coordinate system may be established by features that represent points or lines. Points may be represented by tooling holes, into which target nests or tooling balls are inserted.

Sometimes it's necessary to move the tracker to a second location to measure all the features which are of interest on an object. A convenient

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way to do this is to position three or more SMR nests on or near the object. The tracker measures the coordinates of the SMR in each nest before and after the tracker is moved. Data collected after the move is automatically transformed into the local coordinate system by the tracker software.

A number of accessories add to tracker capability. Remote control allows an operator to make tracker measurements without walking back and forth to the computer. Target-tooling accessories help speed difficult measurements. Air temperature sensor accessories compensate for temperature fluctuations in the environment.

Material temperature sensors help compensate for thermal expansion of the objects measured. An inclinometer (level) measures the tracker's orientation with respect to gravity.

TRACKERS IN THE MANUFACTURING ENVIRONMENT

Trackers are used in all stages of manufacturing: inspecting large milling machines and the parts they produce; building and periodically inspecting manufacturing tools; and carrying out many other tasks. The tracker checks the accuracy of a milling machine that executes arbitrary movements by measuring the position of an SMR attached to the mill's collet. Parts manufactured by the mill are also inspected by the tracker, either before or after production.

Manufacturing tools are also known as fixtures or jigs. Examples are assembly tools, which aid in assembling the final product, and forming tools, which aid in forming metal parts. The tracker assists in the construction of a manufacturing tool by locating alignment features such as holes, pins and edges. Afterwards, it helps perform periodic inspection of the tool's dimensions, contours and features.

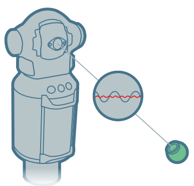
A tracker with ADM capability can perform "point and shoot" measurements to monitor the relative position of large components that are being joined together. This is done by measuring the positions of multiple small retro reflector targets mounted on the components.

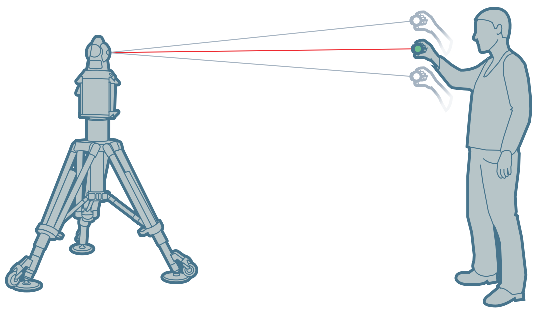
As a specific example of tracker use, consider the creation and inspection of a die in the automotive industry. Designers first create a model of the automobile in clay. The tracker digitises the model's surface, and a computer converts the cloud of points into a smooth surface. From this information, a die is milled and then modified as needed to produce the desired part. During this process, the tracker measures both the die and the stamped part.

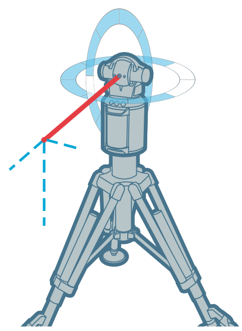
An emerging application for trackers in manufacturing is directly controlling mechanical devices such as milling machines. By controlling the motion of such machines, the tracker ensures that the final manufactured parts meet specifications, thereby speeding the manufacturing process, reducing waste and eliminating redundant testing. Non-manufacturing applications for trackers include precisely aligning and fabricating large-scale structures such as electrical turbine generators and particle accelerators.

Laser trackers' accuracy and speed distinguish them from other portable coordinate measuring instruments.

Because an operator can make rapid measurements with a minimum of advance preparation, trackers are among the most versatile of the coordinate measuring instruments. Tracker software analyses tracker data and presents the results in a useful form. Trackers are becoming increasingly popular, especially for large-scale manufacturing, where they assist in every stage of the manufacturing process.







FARO UK
The Techno Centre Coventry
University Technology Park,
Puma Way, Coventry, CV1 2TT

☎+44 24 76 23 61 51
+44 24 76 23 61 50
uk@faroeurope.com