Defining Accuracy

BACKGROUND

Measurement instruments and systems evolve constantly, enabling the user to take advantage of a whole host of features. The technical specifications of most measurement systems may include reference to such entities as resolution and repeatability but will always include reference to the term accuracy.

This white paper is intended to inform the reader of the meaning of accuracy in the context of metrology in general and in particular for the use of a laser tracker instrument.

This paper will describe the term and will also distinguish between in-line (or radial accuracy) and angular accuracy. Also described is the tendency for the angular errors to dominate during the measurement of a typical object and examples are offered to illustrate this.

Finally, the consequences of poor angular accuracy in particular are outlined.

ACCURACY

Accuracy, or bias as it is sometimes called, is a term which can be described as the closeness of the agreement between the result of a measurement and a true value of the particular quantity being measured. In reality, we will never know the true value of the measured quantity which is why in cases where more certainty of the measured quantity is important, there tends to be an emphasis on ensuring that at least the accuracy of the measurement instrument is optimised.

LASER TRACKING INSTRUMENTS AND ACCURACY

Laser tracking measurement instruments are very versatile by nature, although their use is frequently for applications where there is a demand for the highest possible performance from the measurement system to characterise the object being measured.

One of the reasons why laser trackers have evolved into this high accuracy sector is because of their outstanding ability to accurately measure distances. This was initially due to the use of laser interferometers (IFM) followed later by Absolute Distance Meters (ADM).

Distance measurement capability on its own is not enough if a set of coordinates is required. In order to achieve this, the laser tracker instrument in its basic form is equipped with an angular measurement system to enable the distance measurement to be processed alongside two measured angles to arrive at the required coordinates.

It is clear then that in order for the ever-increasing customer specifications to be met, there has to be an emphasis upon the accuracy of both the distance and angular measurements of the instrument.

SPECIFICATIONS FOR DISTANCE AND ANGULAR MEASUREMENT ACCURACY

Dependent upon the manufacturer of the laser tracker, specifications over the last few years have varied in the sense of their presentation, usefulness and practicality to the user.

The introduction of the ASME B89.4.19-2006 standard has helped manufacturers to standardise the approach toward specifying, although there is some way to go in order that complete agreement is reached across continents.

The ASME standard offers the concept of Maximum Permissible Error (MPE) to the manufacturer and subsequently the user. MPE is useful in the sense that it encompasses the extreme values of error that are permitted by a specification.

The following is a typical distance measurement specification offered by a manufacturer. Please note that actual numbers are for reference only:

For the IFM system:
4 micrometers + 0.8 micrometers/metre

For the ADM system:
20 micrometers + 0.8 micrometers/metre

For the Angular or more often called the Transverse system:
36 micrometers + 0.6 micrometers/metre

Note that in all cases there are two terms - the first term is the offset, while the second term is the slope or scale factor. The slope or scale factor is predominantly a function of distance; therefore it should encapsulate the range of specified environmental conditions together with the specified range of the instrument.

The MPE specifications can sometimes be offered as "Typical", in which case they constitute a halving of the full MPE value for the purposes of portraying a value which will be typically achieved the majority of the time.

As for the relevance of the MPE specs to the user, it's clear that the declared MPE values can be compared to assess the relevance of the purchase across manufacturers. If Point-to-Point accuracy is of interest to the user, some manufacturers publish the formulae used to calculate the MPE, making it possible for the user to calculate his or her own situation.

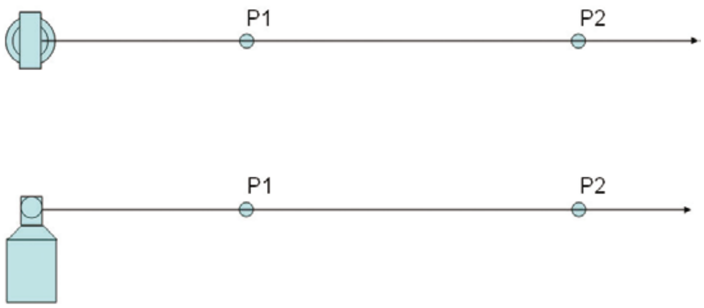
Some manufacturers also offer to certify the instrument with respect to the B89.4.19-2006 standard. If this is available, together with processes to protect or guard-band the MPE specifications, it can only be of benefit to the user.

DISTANCE MEASUREMENT (RANGING) ACCURACY

As mentioned previously, the distance measurement systems typically found in a laser tracker are an IFM and ADM or even ADM only. Independent upon whether IFM or ADM systems are being used, the ability of these systems to detect and measure displacement is well known and documented.

Interferometers were typically used to measure the displacement between two points and therefore the product would be a distance between the two points. It follows that in order for a laser tracker instrument to measure distance optimally, it needs to be positioned in line with the points to be measured. In this case there is no influence from the angle measurement system.

Figure 1: In-line concept to achieve highest possible distance or ranging accuracy



ANGULAR (TRANSVERSE) MEASUREMENT ACCURACY

The angular accuracy of a laser tracker describes how well the instrument discerns angle measurements from its angular measurement encoders prior to processing them together with the distance or ranging element in the form of a coordinate. Figure 2 below shows the theoretically possible deviations at the distances shown from a laser tracker that is operating within an effective angular specification of +/-0.5 seconds of arc.

Figure 2
Angular Measurement Accuracy versus Distance

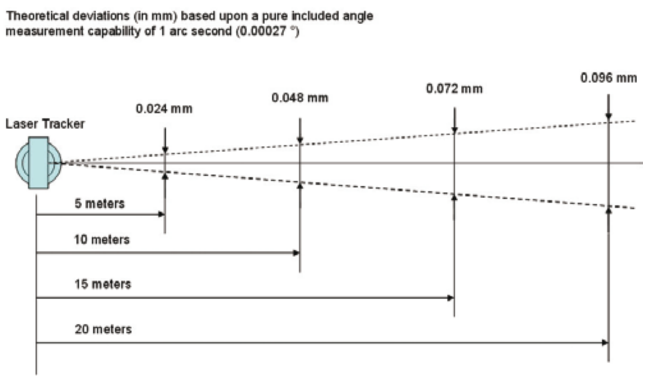
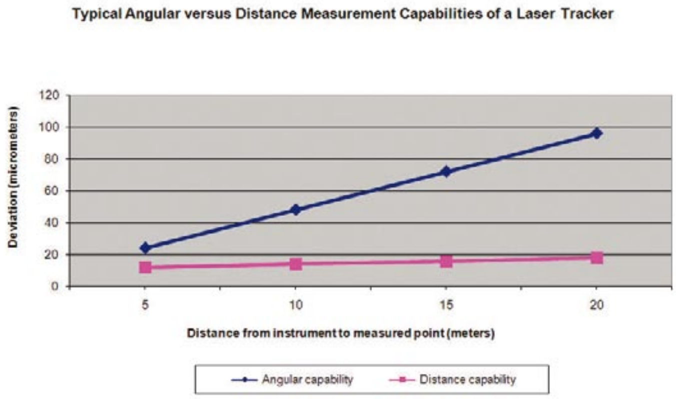


Figure 3 below shows the comparable accuracies between a typical ADM distance specification (e.g. 10 micrometers + 0.4 micrometers/meter) for a laser tracker against a typical angular performance of +/- 0.5 arc seconds as depicted in Figure 2.

Figure 3



With some laser trackers specified out at ranges of 50 meters or more, you can see that the pure ability for the unit to accurately measure angles is very important for respectable performance in the field. This becomes more or less important depending upon the volume of the object and where it is practical and economical to position the instrument in order to measure the points of interest.

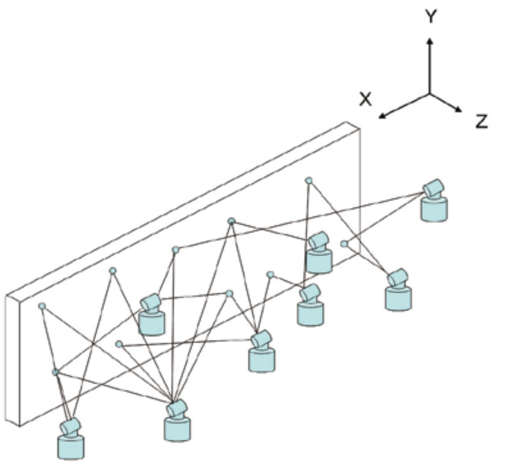
VOLUMETRIC ACCURACY

Volumetric accuracy is often used as a term to describe how accurate the instrument is for a particular measured volume. Where they exist, illustrated concepts of volumetric accuracy from manufacturers have to be aligned with the ability of the user to practically position the instrument in the real-life situation for their particular measured object.

Where measurement volumes are large it is sometimes more efficient for the user to reposition the instrument in strategic and practical positions to enable the viewing of all the required points of interest. The use of more instrument stations will have the effect of reducing the distance from the instrument to the points of interest which will also tend to weight the contribution of the angle measurement. This is especially true if there are practical limitations for the positioning of the instrument, placing more emphasis on the angular measurement capability in the quest to achieve an accurate set of coordinates.

Figure 4 shows a situation where the angular measurement capability of a laser tracker is exposed more so that the distance (i.e. angular errors) dominates.

Figure 4
In this scenario the following is relevant:



- The laser trackers have limited room to maneuver in the Z direction.

- All points of interest cannot be seen from a single position.

- Multiple laser tracker positions are required to achieve the required accuracy.

- The highest possible accuracy is required.

- The measurement volume dictates that the laser tracker angle measurement capability is exercised, especially in the Y (vertical) direction.

Measurement distances have been cut, but laser tracker angles are exercised more severely.

In order to illustrate how much angular errors dominate for a measured object, consider Figures 5a and 5b.

Figure 5a
Points on measured object in line with the laser tracker

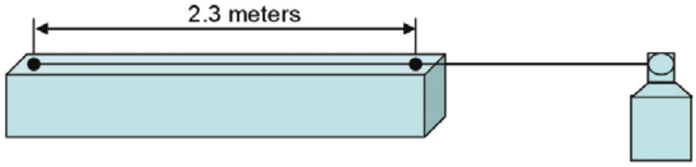
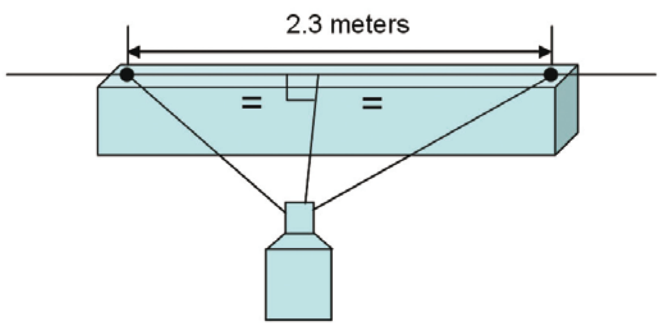


Figure 5b
Line between two points on the object perpendicular to the laser tracker



If the laser tracker in Figures 5a and 5b above is deemed to be 2 meters from the measured object, the following typical MPE performance is attained from a measurement of the 2.3 meter length.

Assume use of **IFM** and a **Typical MPE**

Figure 5a = 3 micrometers

Figure 5b = 33 micrometers

Note the relatively large difference - this is because in Figure 5b the laser tracker's relative position to the points which require to be measured dictate that the angular or transverse measurement system errors dominate.

Objects with features which require measurement are rarely offered up as depicted in Figure 5a. Objects tend to be more irregular in shape and size, and very often not all points can be viewed from an in-line position. Typical examples might be large assembly tools for the aerospace industry.

Figure 5b orientation is more common with the scenario shown in Figure 4 coming into play if not all points can be seen from one position. The moment that multiple laser tracker positions come into play coupled with objects positioned to the laser tracker as depicted in Figure 5b, means that the angular measurement system errors dominate.

It can therefore be concluded that the specifications and actual performance of the angular or transverse measurement systems onboard the typical laser tracker play a very important role in its day-to-day performance for the average user. It's very easy to forget this fact when confronted with the specifications and by the outstanding performance of modern IFM and ADM distance measurement systems.

SELECTED CONSEQUENCES OF SUB-OPTIMAL ANGULAR ACCURACY

Examples of sub-optimal angular accuracy are apparent for large assembly tooling within the aerospace industry. If angular accuracy is sub-optimal, the following could ensue:

- Poor initial reference system leading to a lack of accuracy and repeatability when setting and certifying the tool

- Poorly fitting parts leading to cost issues downstream of the assembly process

- Costly rework based on a poor signal from the measurement system (costs include labor and time tying up a tool which is on critical path).

If the angular accuracy is optimised, it is more likely that the tool will not have to be reworked during its first recertification due to measurement variation at least. Reworking tools such as these described can cost several thousand dollars.

CONCLUSION

Understanding accuracy terms is an important aspect of selecting the best instrument for a particular application. In the case of laser trackers, distance accuracy specifications are often not achievable in the end user's application due to the limited measurement conditions that would be required. The majority of the time the laser tracker user is most interested in measuring points and dimensions that require movement of the encoders and place the application into the volumetric accuracy case. Thus it is the volumetric performance of the instrument that is most critical when considering a laser tracker for the majority of applications.

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