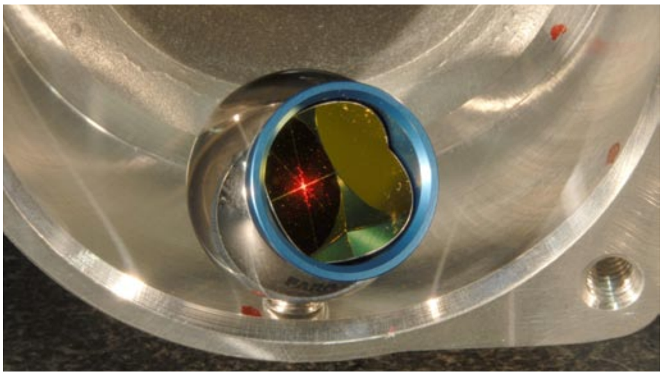
Understanding Laser Tracker Targets

ABSTRACT

The quality of laser tracker measurements is reliant upon the precision of the target. This paper will explain the types of laser tracker targets available and will allow the reader to understand when certain targets should be used, the critical properties of laser tracker targets and the impact they can have on their measurements. First, the paper will establish how laser trackers measure distance (Interferometer and Absolute Distance Meter) and how the target's characteristics can impact the measurements. Three types of targets (along with how they are constructed) will be covered including spherically mounted retroreflectors (SMRs), cateyes, and repeatability targets, with the most attention given to the open air SMR.

It is very common for SMR manufacturers to place special emphasis on the centering of the optics in their specifications. Some users may not be aware of the impact that other SMR specifications such as sphere properties, dihedral angle error, maximum dihedral angle difference, wave front distortion, and polarization can have on measurement performance. A real-world example will be given to illustrate the impact of the design of Break Resistant SMR can have on the SMR performance over temperature.
Finally, the reader will learn how to determine if their SMR is still in tolerance and SMR best practices – how to obtain the best accuracy with the measurement system.

Figure 1: Spherically Mounted Retroreflector



WHITE PAPER

Cooperation is commonly defined as "the process of working or acting together, which can be accomplished by both intentional and non-intentional agents".[i] It is the concept of a cooperative target that sets laser trackers apart from non-contact laser measurement systems. The laser tracker and its target comprise a system that together determine the tracking performance and, most importantly, the accuracy of the measurement. The focus of this discussion will be the intentional and non-intentional contributions that the targets have on the laser tracker system.

HOW LASER TRACKERS MEASURE

When considering the overall laser tracker system performance we need to review the critical elements of laser tracker measurement. Laser trackers determine the distance and angle to the target to calculate the 3D coordinate. These two components are called the radial and transverse measurements respectively.

Two different technologies can be used to measure the radial distance to the target; the oldest being an interferometer (IFM) and the most recent advancement being the absolute distance meter (ADM). IFM systems split a red laser source into a reference and measure component where the reference beam is kept inside the tracker and the measure beam is sent out of the tracker, reflected off the laser tracker target, and returned to the laser tracker. Once the measure beam is returned to the tracker, it is combined with the reference beam and an optical interference pattern is created. It is this interference pattern that enables the radial measurement. The interferometer is expecting the returning beam to be strong and undistorted on its trip to and from the target so that the interference pattern is created accurately and crisply. An ADM system requires the same performance from the laser tracker target: return the beam undistorted and with strong intensity with no echoes or false reflections, so the multiple phases of the infrared beam can be resolved into the radial distance.

Transverse measurements are made using angular encoders and a position sensitive detector (PSD) that captures laser light returned from the retroreflector. The laser beam exits the tracker, travels to the retroreflector, and retraces its path back to the tracker.

All laser tracker target geometries are designed to reflect the laser beam parallel to, but possibly offset from, the outbound beam. The energy of the reflected light on the PSD tells the tracker the offset from nominal. The offset value is used for two purposes – first to drive the laser beam to the center of the retroreflector target, and second to correct the angular encoder readings to account for the velocity of the SMR. The design of a PSD requires a round, Gaussian shaped beam so that the center of energy represents the center of the target. If the beam's shape is distorted by the target, then the PSD can be misled in its effort to provide an accurate offset to the measurement systems.

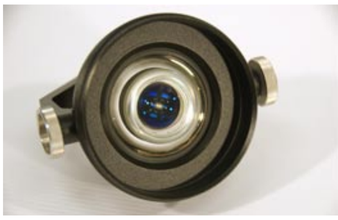
The job for the laser tracker target is a simple one: return the laser beams exactly as they are sent from the tracker. To achieve this goal, the target needs to be designed and manufactured to incredible tolerances yet be suitable for use in real world manufacturing environments that vary in temperature and cleanliness. In addition, the retroreflector should be able to survive some abuse in handling – possibly even an occasional drop on a concrete floor.

LASER TRACKER TARGETS

Laser tracker targets are complex mechanical structures of precision optics, precious metals, high performance adhesives and near perfect geometry. The primary goal is to return the laser beams with the highest intensity while not distorting the beam as it is reflected and/or refracted off of the various geometric surfaces of the target.

In practice it can be difficult to maintain the required build tolerances and manufacturing processes for consistent production of these opto-mechanical systems. It is critical that every target is evaluated by sophisticated instruments to validate the individual performance. It is important that laser tracker operators understand the various specifications of tracker targets and how deviations can contribute to poor tracker performance or errors in the measurements. The construction and typical problems will be discussed for the three most common types of laser tracker targets: cateyes, repeatability targets and spherically mounted retroreflectors (SMR). Special consideration and a full exploration of the SMR will be given as it is the standard target used for most laser tracker measurements.

CATEYE TARGETS



Cateyes are spherical reflectors that are designed for wide acceptance angle applications. The most common design for this most rare and expensive of all tracker targets comprises two hemispheres of solid glass. The front hemisphere is smaller and refracts the laser beam toward the center of the sphere. The laser beam then passes to the larger, rear hemisphere where it is reduced to a very small spot on the rear surface of the sphere. It reflects off this surface and travels back through the hemispheres, emerging as a collimated beam of light that travels back to the tracker. The spherical geometry of this target provides up to a 120 degree acceptance angle which is two times larger than a standard SMR. A critical consideration when selecting a cateye target is the wavelengths of the lasers emitted by the tracker. In the same way that a prism separates white light into the colors of the rainbow, the cateye separates the reflected beam by wavelength. The optical properties of cateyes mean that focal length changes with wavelength and this necessitates that both the ADM and IFM wavelengths are close enough together that they both reflect back to the tracker. With some trackers, the ADM wavelength is different enough from the IFM wavelength that it is refracted along a different path though the cateye and reflected away from the tracker so that no distance can be set by the ADM system. Several attributes are critical in the design and construction of cateyes. If the cateye is not constructed properly or if the design tolerances are not met then it can induce measurement error at the extreme angles. The most common contributor to errors is the laser beam clipping on the edge of the cateye. Other errors can be caused by manufacturing variations where the two hemispheres are not centered properly and the beam will not return round, but oblong. Other aberrations in the beam can be caused by a non-uniform bond layer or areas of the glass surface that are not spherical. Generally, cateyes are constructed very well and the operator only needs to be concerned about not clipping the beam in an effort to maximize the acceptance angle of the target. It is possible to still track while beginning to clip the beam so care must be taken in the use of a cateye target.

REPEATABILITY TARGETS

Repeatability targets and spherically mounted retroreflectors (SMR) use the same geometric shape to reflect the laser beams to the trackers. Often referred to as a corner cube, it is comprised of three mutually perpendicular surfaces. The laser beam reflects off each of the three surfaces and returns offset and parallel to the incident laser beam. As the name indicates, the surfaces look like a corner of a cube and can either be solid glass or open air. For the open-air corner cube, the "cube" is air bounded by three primary mirror surfaces. The properties of the corner cube retroreflector will be discussed in detail with regard to the SMR target. The critical distinction between repeatability targets and SMRs is that SMRs, by definition, contain a retroreflector precisely mounted in the center of a sphere, while repeatability targets are not centered in their mounts to any significant tolerance. Repeatability targets are generally used in large quantities to study the change or drift in an object over time or use. These studies are referred to as surveys and are used to investigate temperature impact, mechanical deformation under load, dimensional changes through repetitive use, and for many other applications. Only the relative change in the XYZ coordinate is required in these cases – they are required to provide a repeatable value in a static position, not an absolute XYZ value.

Several vendors make different types of repeatability targets for different price points and applications. These targets cost less to manufacture because of the reduced precision required in the retroreflector mount. However, the corner cube must return laser beams of the same quality and intensity as other retroreflector targets. Both the shell and the corner cube can vary in repeatability targets from different vendors. The shell can be spherical or take the shape of a cylinder with a spherical end. The rounded end is not precision as in an SMR but is designed to allow the repeatability target to be aimed easily at various angles – typically with hot glue for temporary applications or epoxy for more permanent situations. A more recent development is an adjustable metal clamp mount and a window covered retroreflector that can be used outside in harsh environmental applications where weather and vibration are a concern. The retroreflector can be solid glass or open air and the differences will be covered in a later section. Modern repeatability targets have to be designed within tight requirements for high precision optical performance and a low price point when hundreds of targets are needed to support critical applications.

SPHERICALLY MOUNTED RETROREFLECTORS

The Spherical Mounted Retroreflector (SMR) is the staple of laser tracker measurement with the majority of users never requiring any other target type. Unlike repeatability targets, the spherical mount is as critical as the optics it carries. The most precise applications are pushing for every micron of accuracy possible so every element of the SMR is critical. The most accurate SMR models require the highest precision and quality spheres, near perfect geometry and clarity of the optics, assembled with processes that hold mere microns as tolerances. These state of the art opto-mechanical assemblies are verified by high performance instruments in temperature controlled rooms to confirm that design criteria are fully met. When combined with modern laser trackers, unbelievable accuracy and range enable some of the most impressive engineering projects in the world. Considering the importance of the SMR and its contribution to the accuracy of laser tracker systems, it is a disservice that most vendors simply supply a specification on how accurately the optic is centered in the sphere when so many other properties impact the overall performance. The best laser tracker in the world is only as accurate as the SMR being used.

There are three basic configurations of SMRs: solid glass retroreflector, open air retroreflector and a version of the open air SMR that has a window covering. The following sections will discuss the construction and properties of the components used to assemble these different styles of SMRs.

SPHERE PROPERTIES

It all starts with a solid stainless steel sphere. SMRs are expected to be accurate and durable and it is the steel sphere that provides the contact surface for the measurement and protects the optics from damage during use. Different alloys of stainless steel are used to balance magnetic properties against corrosion resistance. Steel spheres are categorized into grades that describe their dimensional properties. A common ball grade for an SMR is Grade 25. The number 25 refers the sphericity in millionths of an inch (.000025"). The other properties of the ball are also controlled by the grade specification. A grade 25 ball specifies a surface roughness tolerance of no more than .000002" and a diameter tolerance of +/-.0001".

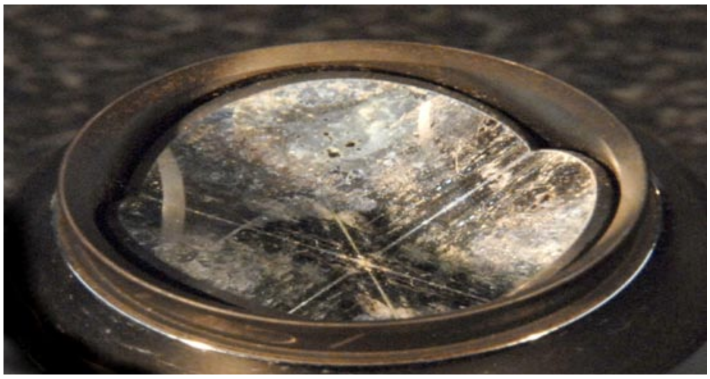
CORNER CUBE RETROREFLECTORS

The heart of the SMR is the corner cube retroreflector. Four types of retroreflectors are used in SMRs: solid glass, glass panel, single element, and integrated into the sphere. Each type has advantages and disadvantages based on the application, cost and performance requirements. Solid glass retroreflectors are relatively easy to manufacture so SMRs built on this design represent some of the most economical options. Any time light travels through glass, errors are induced due to the bending of light so some vendors offer extended collars that reduce the acceptance angle to control these errors. In addition, to minimize the errors, the glass cube corner should be as small as possible. In other words, glass corner cubes should only be used in small SMRs. Some laser tracker ADM systems are sensitive to reflections of the laser beam within the corner cube when the beam is nearly perpendicular to the front surface. Unfortunately, near normal incidence, where angular errors are minimized in glass corner cubes, the risk of ADM error is greatest. To manage the possible ADM errors, special coatings can be applied to the front face of the glass corner cube. These coatings need to be matched to the laser wavelength to be effective. Caution needs to be exercised when considering solid glass retroreflectors not supplied by the tracker vendor as different trackers have very different ADM wavelengths and all are not compatible with this target type. In addition to the cost advantage, solid glass retroreflector SMRs are more break resistant than traditional glass panel SMRs providing a low cost, durable option if compatible with the laser tracker. Solid glass retroreflector SMRs are a patented configuration, and so they are not offered by many vendors.

REFLECTIVE SURFACES

Open air retroreflectors are the most common type due to the advantage of not having any errors introduced by the laser traveling through glass. There are two styles of reflective surfaces: protected silver and gold. Traditional glass-panel SMRs have mirrors with a silver reflective surface with a clear protective coating to prevent oxidation of the silver. While the protective coating provides a durable surface that reduces scratches during cleaning, the laser light travels through this coating and the beam characteristics can be influenced if the coatings are not of the proper thickness or uniformity. Another disadvantage is that a pinhole or micro scratch in the protective coating can lead to catastrophic failure of the reflective surface as humidity can enter through the opening in the coating and silver oxidation can propagate under the protective surface.

Figure 5: Oxidation of Silver Surface



Gold coatings are primary reflective surfaces and are not susceptible to oxidation as is silver. The gold color is also more reflective to some ADM wavelengths and will enable longer range performance. Gold surfaces are more susceptible to scratches during cleaning but comprehensive tests have shown that these micro scratches do not impact SMR performance.

SMR CONFIGURATIONS

Historically, SMRs have most often used glass panels. The balance of precision and price of these SMRs has made them popular. Assembled from three flat glass panels bonded together, they are offered by multiple vendors. Before they are assembled into corner cubes, the flat glass panels are coated with protected silver. The panels are often matched to minimize polarization effects and reflectance variation. The three glass panels are bonded into an assembly, which is centered in the sphere. When manufactured carefully, glass-panel SMRs represent some of the highest performance targets available. The major weakness is the glass panels themselves. Easily broken if dropped or not handled carefully, glass panel SMRs are considered a consumable by some users. The challenge in using these targets in critical applications like calibration labs is that they need to be monitored carefully for changes in their geometry and recertified more frequently than other target designs. Through the common handling abuse that may occur during daily use, the adhesive can release the whole optical assembly or a single panel within the assembly can shift from its nominal position. This can distort the beam and lead to errors in measurements. Through the use of many glass panel SMRs in a calibration lab accredited to perform B89.4.19 laser tracker tests, these changes have been documented; leading to the development of a new target style having high centering accuracy and geometries that are more stable over time.

Break resistant SMRs are a newer configuration and are becoming more popular due to their robust design and consistent performance quality. The key issues that have limited their broad acceptance are reduced centering accuracy and greater expense. There are two types of break resistant targets. The first type is the integrated optic SMR. The design is a solid steel sphere where the retroreflector is machined directly into the sphere. Creating the three mutually perpendicular surfaces into a hardened sphere requires time and expensive processes that lead to the higher costs. The optical reflective surfaces are transferred into the sphere through a process called replication. A replicated optic begins by coating a master with gold as an optical surface and release agent and then a thin layer of epoxy. The machined metal is referred to as a substrate and is pressed onto the master and allowed to cure. The adhesive layer takes up any variation in the surface of the substrate leaving a precise copy of the master when removed from the tool. While this design represents the most break resistant and stable design, machining of the hardened steel has limited the possible accuracy. Unlike glass panels having surfaces that are stiff and flat, replicated optics have surfaces that are soft and can be damaged through aggressive cleaning. Because the entire SMR is made almost entirely of steel, with only a thin epoxy layer, the integrated optic SMR design has proven to be the most stable over extreme temperature changes. Early versions of this design had issues of collars breaking off as the collars were not threaded on but bonded with an adhesive. The issue seems to be resolved at this time by the vendor as no failures have been noted for a couple of years.

Figure 6: Single Optic Break Resistant SMR

The second and newest type of break resistant SMR features a single replicated optic mounted into a hardened stainless steel sphere. The optic is manufactured in a replication process similar to that of the integrated optic SMR, with the difference being the substrate material. In place of the difficult and expensive to machine hardened steel, aluminum is used for the substrate. The single optic is an aluminum cylinder with the three mutually perpendicular faces machined and the gold reflective surfaces applied through replication. Because the optic is easier to manufacture it offers a middle ground in cost yet retains the break resistant properties of the integrated optic SMR. The assembly process is similar to that of the glass panel SMR in that the retroreflector is centered in the sphere and secured by a high performance adhesive. The design allows for very precise centering, yielding an SMR with high accuracy and break resistance. In significant testing of this new configuration it has been found that the centering of the optic and the angles of the reflective surfaces are maintained through multiple drops. When engineered properly, the retroreflector will either hold its position accurately or completely fail and fall out of the sphere. This behavior is preferred as the user has confidence in the performance of the target unless there is a catastrophic failure.

Another patented SMR configuration is a glass window covering an open air retroreflector. The glass covering offers the ultimate protection in very dirty environments where it can be cleaned as required without the potential damage of cleaning the delicate optical surfaces of the retroreflector. As is the case before, the laser beam passing through the glass window bends or refracts the beam. The potential error from this effect is reduced almost entirely by changing the centering position of the retroreflector. The laser tracker firmware applies a compensation factor to the radial distance to accurately compensate for the window thickness. The window is coated with thin dielectric layers to reduce unwanted reflectance of the ADM light. Recent developments feature a break resistant retroreflector with the window covering. The resulting SMR is accurate, environmentally protected, and break resistant. If the SMR is dropped, the window can be replaced by the user and work can continue with only minor expense.

SMR PROPERTIES AND MEASUREMENT UNCERTAINTY

Understanding how SMRs are constructed provides the required background to understand how the different SMR properties can impact the laser tracker's ability to track and measure to the fullest of its capabilities.

The stainless steel ball can contribute to measurement uncertainty if the sphericity or diameter is not known accurately or if it becomes worn and develops flat spots or areas where the diameter is not nominal. It is critical that the operator considers the ball grade when calculating the measurement uncertainty.

The radial measurement systems are susceptible to polarization errors in an improperly manufactured SMR. The most common cause of polarization error is the uneven application of the protective coatings on protected silver retroreflectors. Most laser tracker systems are sensitive to polarization in one mode or another. If the SMR causes the polarization state to change and the IFM system requires a certain state, then the optical interference pattern may not be created clearly. Some laser trackers utilize a polarization modulation technology for their ADM that could be impacted by a changed polarization state of an SMR. Mirrors with poor reflectance from poor coatings or damaged optical surfaces will return a weak signal. In this case, the SMR may track poorly or, more importantly, the ADM or IFM system may have reduced measurement accuracy.

The transverse measurement performance can be impacted by the SMR as described in ASME B89.4.19-2006 Appendix B. The B89 document discusses 3 types of SMR uncertainty contributions. The first two are mechanical properties related to the lateral and radial centering of the retroreflector in the sphere. It is the third property that is least understood – dihedral angle errors[ii]. The dihedral angle error is the deviation in the angles of the adjacent panel from perpendicular.

This deviation can cause measurement errors in trackers for the case in which the PSD "retrace point" is not properly set. Laser trackers are compensated to establish the retrace position but this compensation is not perfect. Consequently, it is critical that the SMR is manufactured to a specific dihedral angle tolerance and that these dihedral angles are maintained over use. The simple explanation of the condition in B89.4.19 Appendix B is where one or two of the SMR panels have a high dihedral angle error in respect to the others. As a result, the optical center can be shifted and not represent the mechanical center of the retroreflector. The offset beam will cause the apparent center of the beam to change as the SMR is rotated in a nest. This type of error is called runout error and may be the result of either the cube corner within the sphere being off center or a dihedral angle error. However, the runout patterns have a different appearance when the cube corner is off center and dihedral angle error, as is explained in the B89.4.19 standard, Appendix B.

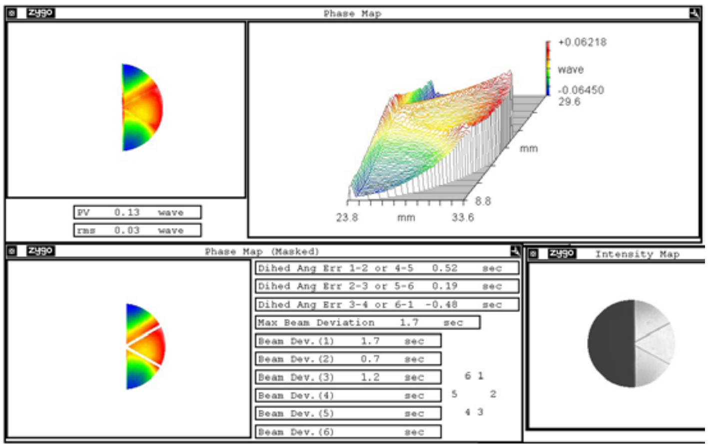


Figure 7: Interferogram Demonstrating Dihedral Angle Error

Another dihedral angle error occurs when all three panels are tilted into the center or away from the center. These conditions will cause the reflected beam to either expand or contract more than expected when it returns to the tracker. If the beam becomes expanded enough on the return, it can clip on the optics and cause the beam on the PSD not to be round (Gaussian) as required.

SMR SPECIFICATIONS AND ERRORS

Beyond the standard centering errors that are commonly reported on SMR certification sheets, there are several other specifications that are critical to an SMR's performance. To review, an SMR is supposed to return the laser beam to the tracker without added distortion. SMR induced errors can be the result of dihedral angle errors, as described above, or wave front distortion.

Dihedral angle errors are generally reported with two values: total error and adjacent angle error. As discussed in the prior section, total error can cause the beam to expand or contract on the return path to the tracker. This may cause the beam shape to distort. Adjacent angle error, on the other hand, can lead to a shift in the optical center of the beam and produce optical runout when rotating the SMR.

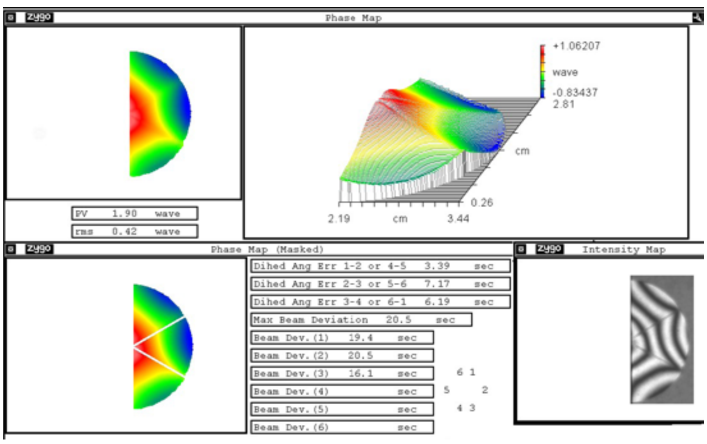


Figure 8: Interferogram Demonstrating Wavefront Distortion

Wavefront distortion is a measure of the change in the wavefront shape as a result of reflection off the mirror panels of the SMR. It may be caused by panels that are not perfectly flat. When the laser beam is reflected off an SMR having panels that are not flat, the wavefront is altered from its original flat form. This can result in increased error in the systems of the tracker, including the IFM, ADM, and angle measuring systems. The term wavefront distortion is a composite measurement that includes effects due to panel flatness and dihedral angle errors since both effects influence the wavefront of the laser beam returning from the retroreflector. Within the reflective region of the SMR, the center of the target is the most critical as this is the area where the power that the laser beam conducts is most concentrated. A specification that quantifies the quality of the retroreflector in this critical region is called central wavefront distortion. This specification considers wavefront quality over just the central 6mm region of the corner cube.

REAL WORLD EXAMPLE

As a tracker vendor that supplies targets that are both manufactured internally and supplied by several different vendors, we are required to test the performance of all targets that we supply to customers. From these tests we have developed a database of thousands of laser tracker target test results. These tests include individual target certification, as well as tests of broader performance requirements that cover the extreme environmental range and operational abuse. As part of the validation testing on a new SMR configuration – the single-optic break resistant model – a very interesting engineering challenge emerged. To meet the customer requirements, the SMR needs to maintain the required performance over the temperature range of the laser tracker and not be permanently altered at the even more extreme potential storage temperatures. The requirements for possible storage temperatures were determined to be -40°C to 70°C for this testing. While the laser tracker's operation is limited to -15°C to 50°C, the target needs to be able to be subjected to these extreme storage temps and return to the in tolerance specifications and geometry for the operational temperature range.

The single optic SMR is comprised of three elements for the consideration of this specific test: the stainless steel sphere, the aluminum replicated optic and the adhesive layer bonding the two together. Individual testing demonstrated that the sphere and retroreflector maintained acceptable geometry and returned to the original dimensions after temperature cycling. Part of the challenge was selecting an adhesive flexible enough to hold the optic in the proper position over the operational temperature range while withstanding at least 10 drops to a concrete floor from a standard operating height. At the same time, it had to be stiff enough to maintain the cube corner at the same position over time. The initial prototype samples performed great through the drop tests and operational range temperature testing.

The challenge occurred after the storage temperature cycle test. The retroreflector dihedral angles changed dramatically and did not return to nominal after the target was returned to ambient temperature. There are two types of mechanical deformation that can occur under strain of extreme temperature changes: elastic and plastic. Elastic deformation was expected and means that the geometry of the SMR may exceed tolerance at the ends of the storage temperature range but return to an intolerance condition within the operating range. What was observed was plastic deformation where the geometry was permanently altered to an out of tolerance condition even when returned to ambient temperatures.

When considering the design of the SMR, the first theories involved temperature induced strain relief of residual machining stresses in the sphere or retroreflector that altered the geometry of the assembly. In consulting with the various vendors it was determined that both elements experienced greater that 70°C temperatures post machining and prior to assembly into the SMR. Extreme temperature exposure to the spheres and retroreflectors validated that they were not changing and final confirmation was accomplished by removing the retroreflectors from the test SMRs and measuring the dihedral angles again. When removed from the sphere, the dihedral angles returned to an in tolerance condition. The result left an improbable explanation for the SMR failure at storage temperature. The thin adhesive layer was being deformed because the steel sphere was expanding and contracting by a different amount than the aluminum retroreflector at the temperature extremes. The adhesive layer was being plastically deformed, producing a stressed condition in the aluminum retroreflector that forced the dihedral angles out of tolerance. To resolve this issue the amount of adhesive, gap size and adhesive properties all had to be reconsidered. After the proper balance was struck among all the constraints, the SMRs were able to pass the temperature tests. The initial failure of the product validation test demonstrates how dependent laser tracker targets are on well tested and well engineered designs. After manufacturing and testing in the lab, the original design performed exactly as expected.

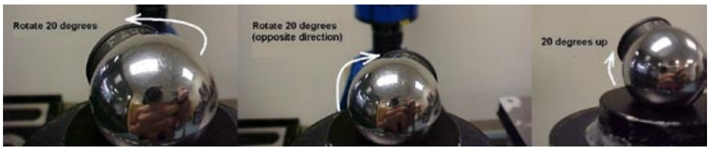
A customer, after leaving the SMR in the car over lunch on a hot southwest summer day, could find their laser tracker not tracking as well as it did yesterday or, worse, not making accurate part measurements. Most operators and technical support teams would not suspect a change in SMR geometry to be the cause of a tracker problem, but we continually learn that when microns count, you must test everything.

FIELD CHECKS

Considering the potential of the SMR characteristics changing due to use, abuse, manufacturing defects or poor design, it is in the best interest of the operator that the SMR is quickly checked before every critical measurement job. In the event that the SMR does fall, the same test can be used to verify that it was not damaged and the measurement session can continue. A basic field check includes SMR runout and depth error tests. A good quality nest is required to perform these tests. Check the nest for damage and cleanliness as magnetic dust can collect on the contact points and offset the SMR in the nest. Secure the nest at the same height as the tracker 1-2 meters away.

Runout: Place the SMR in the nest pointed at the tracker with the serial number or logo facing upward. Take a point with a minimum of 1000 samples, 2000 would be the preferred if time allows. Rotate the SMR about the axis of the laser beam 45 degrees and take another point. Repeat this process for a total of nine measurements. The SMR should be in the starting position at the end of the test. In any measurement application, best fit a point with the nine points and review the form. Due to the various SMR specifications and tracker accuracies it is not possible to provide a tolerance range for the form error. The tracker vendor should be able to provide an expected error or the operator can test a new SMR in a good environment and use this as a baseline for future runout checks.

Depth Error: Place the SMR in the nest as in the runout test. In this test we want to rotate the SMR in a horizontal plane about 20 degrees to the left and take a point and then to the right about 20 degrees



and take another point. The SMR serial number or logo should face upward for the entire test. The next step is to rotate the SMR in the vertical plane, up 20 degrees for the third point and then negative 20 degrees down if the design of the nest allows for the fourth and final point. If not possible, the forth point can be in the start position. Evaluate the results of this test the same way as the run out test.
This basic procedure confirms that the SMR is not contributing significant uncertainty to the measurement job. A best practice for critical measurements would be to start the session with this SMR test and record the results and then to end the session by repeating the same tests and recording the values again thus confirming that there was not a change in the SMR properties that negatively impacted the tracker's performance.

SMR SELECTION

Several aspects need to be considered when selecting the best laser tracker target for a given application. First the size of the features being measured can dictate that a small diameter SMR would be more effective. The standard SMR size a 1.5" sphere. The most common alternate size is a .5" SMR but the performance of some trackers are limited with this size target as the laser beam can overfill the retroreflector at longer ranges causing the beam to clip and induce errors. A middle size .875" SMR is gaining in popularity as it offers the full performance of the 1.5" SMR but is lighter and easier to handle. When a great number of points are to be observed for drift or changes over time, repeatability targets provide cost savings over standard SMRs.

The environmental conditions such as temperature range or extreme dust problems due to grinding could justify the added expense of an integrated optic or window SMR.

When considering the required accuracy, carefully check all the SMR specifications. The ball grade is not always communicated clearly on technical specifications. Care needs to be taken when selecting a SMR vendor as some have chosen grade 50 balls with a diameter tolerance of +/-.0003" and then center the optic to +/-.0001" and charge a premium for the accuracy. While all vendors' high accuracy products demand higher prices due to the difficulty of producing the product, the purchaser needs to check all the SMR specifications to be sure that the final product can reasonably deliver on the promised performance. The purchaser also needs to be realistic about the setup stability and environment for the application. Most manufacturing environments have vibration, airflow and temperature variations that induce errors that wash out the difference between the standard SMR offering and the high accuracy versions. Only pay for the accuracy you need.

Finally, consider the experience of the operator and the amount a movement in and around tooling or other structures that is required. Break resistant SMRs carry a premium price but the cost of replacing a single broken glass SMR easily justifies the additional cost.

SMR MEASUREMENT BEST PRACTICES

Regardless of the type or precision of the laser tracker target used, following some simple best practices can minimize any errors and ensure that the measurement job is completed quickly and accurately. When measuring, always keep the SMR orientated in the same direction. The easiest practice is to keep the serial number or logo facing up at all times. This practice can minimize the impact of SMR runout errors such as poor centering and dihedral angle errors.

The exception to the rule is when scanning across rough surfaces as the surface of the steel ball can wear causing flat spots that are far greater than any centering accuracies of the optics. Rotate to new sections of the SMR between scanning sections and do not use the area opposite of the serial number to maintain the surface quality of this section of the sphere for the single point measurements.

When placing the SMR into nests or precision tooling, rotate the SMR back and forth a few degrees before taking the point. The movement in the nest will push away any metallic dust or other particles that can cause the SMR not to set in the nest accurately.

As discussed in the prior section, always perform a SMR field check if the target is dropped or abused during use. Try to keep a newer SMR available for diagnosing tracker problems. It is a good practice to rotate the SMR stock based on the intended usage. The newest SMR is the reference SMR and is kept in the case and used for compensations and for troubleshooting tracker issues. The next SMR is used for measurements in nests and single points only. The oldest SMR is used for scanning and when the surface is worn enough or the retroreflector surface is damaged beyond use a new SMR is ordered. The new SMR becomes the reference SMR and the others move down the list.

Finally, only clean an SMR if you have to and are instructed to by the laser tracker system. Very often users will clean an SMR out of a desire to keep it looking new and not because cleaning is required. Every time the delicate optical surfaces are cleaned there is the risk of permanent damage to the SMR. Always follow the vendor's cleaning instructions exactly and only clean when absolutely required.

Laser tracker targets are the modern gems of high performance measurement. Pushing the limits of material science, high precision machining and mechanical assembly, they are contributing in a supporting role to the advancement of large scale metrology.

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[i] *From Wikipedia, the free encyclopedia, www.wikipedia.com/cooperation*

[ii] *ASME B89.4.19-2006, Performance Evaluation of Laser-Based Spherical Coordinate Measurement Systems, The American Society of Mechanical Engineers, New York, New York*

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