WHITE PAPER

HEXAGON
METROLOGY

LEICA ABSOLUTE INTERFEROMETER

A New Approach to Laser Tracker Absolute Distance Meters

1.INTRODUCTION

In the ideal world, a laser tracker would combine the ability to instantly re-establish a broken laser beam and immediately start measuring a moving target. At the same time, it would measure absolute distances with the highest precision and would be arbitrarily fast with near zero integration times (the time required to determine the target's position). Until now, no single distancing unit was capable of this. As a result, laser tracker manufacturers were forced to use both laser interferometers (IFM) and Absolute Distance Meters (ADM) separately.

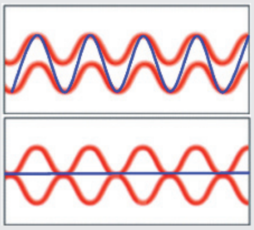


fig. 1

Each individual technology has its own strengths and weaknesses. An IFM can determine relative distances (i.e. the change in distance from point to point) with accuracies on the nanometer level. A laser beam is projected from the system to a reflector, with both the exiting, and returning beams being monitored. As the reflector is moved, the return beam moves, and the wave peaks cross each other creating a superposition wave (fig. 1). Every time this superposition wave peaks, it represents a change in distance of ½ of the wavelength, or in the case of the AIFM, 0.32 microns. This is where the term IFM "counting" comes from: If you know the direction of movement (which is given by the heterodyne setup) and count the number of times that the superposition wave peaks, you can multiply this by ½ the wavelength and calculate the exact change in distance. Not only is this incredibly accurate, but it is also almost instantaneous. The update rate is given only by the speed at which the reflector can be moved. This makes laser interferometers perfect for dynamic measurements, because no matter how quickly the target accelerates, the exact change in location is immediately known to the sub-micron level. They have been an industry standard for over 30 years and remain the most accurate system for measuring large distances available. However change in distance, or relative motion is all that they are capable of measuring. An IFM is unable to determine an absolute position in 3D space without having a known starting point first. An ADM on the other hand, measures absolute distances (i.e. distances to a known point in a 3D coordinate system) with extreme precision, but even the fastest ADM will never be able to achieve the speed of an IFM for dynamic measurements. All absolute distance meters must deal with integration times, the time required to perform the operations that determine the target's position. This is similar to the shutter speed on a camera. The longer the exposure time, the harder it is to take a clear picture of a fast moving object. The same is true with integration time, the longer the integration time, the more likely you are to introduce an error in the measurement of a moving object. An IFM doesn't have this problem. The change in distance is always immediately known. This is what makes the AIFM or "Absolute Interferometer" revolutionary, it can measure absolute distances to a moving target without a loss in accuracy due to target instability during integration.

2.HISTORY

Leica Geosystems was the first laser tracker manufacturer to put an ADM into a laser tracker. The introduction of the LTD500 in 1995 revolutionized the way that laser trackers were used. If the beam was interrupted the operator no longer had to return to a known location to "reset" the IFM distance. The ADM could do it automatically. ADMs quickly became the de facto standard, and within a few years all of the major laser tracker manufacturers had brought some form of ADM technology to market, but Leica Geosystems always remained the accuracy leader. Some of our competitors didn't view accuracy as a key priority, to them speed was more important. The problem with these "fast" ADM systems was that using the ADM considerably decreased the achievable accuracy of the laser tracker. This forced the operators to use the tracker in "IFM only" mode if they wanted to achieve the highest accuracies. Even as these manufactures tried to push the market towards ADM only solutions, they were forced to keep IFM laser trackers in their portfolio to satisfy these high accuracy applications. Leica Geosystems however always put accuracy first; there was no point in having an ADM if it wasn't accurate enough to be used for every measurement. Our commitment to the ADM was further reinforced with the release of our 6DoF technology in 2004. The T-Products required the ADM because they could not be started from a known location the way that reflectors could be. Our dedication to the 6DoF market made our future development very clear. The ADM had to reach the point that it had similar accuracies and dynamic performance when compared to the IFM, and would need to be fast enough to allow absolute distance to be set on moving targets. At the same time it had to achieve a level of accuracy that no operator would ever feel the need to use the system as an "IFM only" laser tracker ever again.

Unfortunately this left us with a considerable trade off, we wanted to build a fast ADM, but we wouldn't sacrifice the accuracy of our previous ADM technology. The technology that was used was without question the most accurate and stable way of establishing absolute measurements over long distances, but it was not very fast. The technology originally came from the Kern Mekometer 5000 (fig. 2) that was used to measure distances up to 8 kilometers (5 miles) with a typical accuracy of 0.2 millimeters + 0.2 ppm. The original ME5000 and the new ADM both use the same unique patented Polarization Modulation principal that is very insensitive to both long distances, and environmental influence. This principal is based on the "electronified" cogwheel discovered by A.H. Fizeau in 1849, and uses frequencies rather than a fixed reference length to determine the measured distance. Not using a reference length means that no additional temperature related drifts of the reference path need to be taken into account. This makes it one of the most stable ways to measure long distances, and often produces single micron standard deviations when measuring fixed points over long periods of time. Even our previous generation ADM was more accurate than any of our competitor's most recent technology when comparing measurements over long distances. The challenge was to take a technology that was already the most accurate in its field, and make it even more accurate, all while trying to achieve dynamic performance similar to an IFM.

3.ACCURACY IMPROVEMENT

The three key parameters that influence the achievable accuracy of this design also affect the shortest measurement distance as well. They are the modulation frequency, frequency bandwidth, and synthesizer (frequency) resolution. The original ME5000 operated at maximum frequency of 510 MHz, with a frequency bandwidth of 20 MHz. The smaller the frequency bandwidth the longer the minimum measurement distance, with the ME5000 requiring a minimum measurement distance of about 20 meters. To make this technology work as the ADM in our previous generation laser tracker, the maximum modulation frequency was increased from 510 MHz to 900 MHz, increasing the frequency bandwidth to 150 Mhz. Increasing

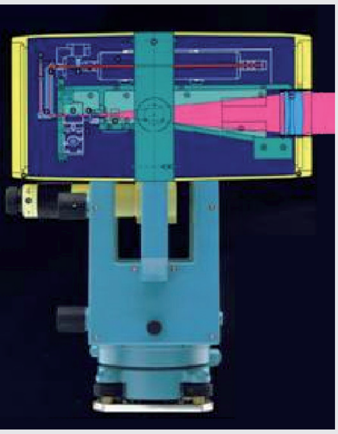


fig. 2

these parameters is like using a better scale to measure with; the higher the modulation frequency and the smaller the synthesizer resolution, the more accurate the achievable result is. The new design in the AIFM has further increased the maximum modulation frequency to 2.4 GHz, with a frequency bandwidth of 300 MHz. This increase in frequency, in addition to an improved high speed synthesizer design which allows for higher resolution of the frequency steps, gives the AIFM a typical accuracy over the full working range of about 5 µm.

By using the polarization modulation of the laser light to determine the distance, any change in the polarization status of the laser beam that is un-accounted for can create an error source. These excess polarization errors are typically very small, in the single digit micron range, but in order to take full advantage of the new increased accuracy described above, even these minute errors would need to be eliminated. We found that by using a broadband light source where light is emitted over a wide range of wavelengths, these errors could be significantly reduced. By changing from a laser diode (monochromatic light source) in the original ADM, to a Superluminescent Light Emitting Diode or "SLED" with a broadband spectrum in the AIFM, these sensitivities to polarization changes all but disappeared. Thus allowing the 5 µm accuracy described above, to be achieved over the entire measurement volume, without limitation.

4.FUNCTIONALITY IMPROVEMENT

There are three main parameters required by our system to be able to calculate a distance; the wavelength of the light source, the speed of light (including the refraction index of the air), and the modulation frequency of the polarized light. This modulation frequency is the key to the ADM, but in order to measure it accurately, we need to analyze the returned wave form for a period of time to determine the minimum point (or the lowest point of the wave). This fine measurement of the wave is a type of wobble measurement that jumps back and forth over the minimum point of the wave to create a measured mean value (fig. 3). Until recently, the reflector had to remain stable during this wobble measurement. If the reflector moved, the wave form moved, and thus the minimum point would move as well. A phenomenon that we were never able to take full advantage of with our previous ADM design, was that, even if the reflector was moving, the wave form wouldn't change shape, it would just move relative to the distance that the reflector was moving. This meant that we didn't actually need the reflector to be stable during integration; we just needed to be able to track its relative movement.

This is where we combine the Absolute measurement from the Absolute Distance Meter with the Interferometer to create the Absolute Interferometer. As soon as a reflector is brought into the laser beam, or "Locked-On", the IFM starts tracking its relative movement. Even if the reflector is moving at the maximum speed and acceleration allowed by the laser tracker, the IFM will still deliver sub-micron positional information to the ADM during integration. The ADM then measures the wave form as described previously, but uses the information from the IFM to compensate for the moving wave form. As soon as the minimum point is calculated, the absolute distance is fed back to the IFM, changing it from a relative interferometer into an interferometer with an absolute reference, or what we refer to as an "Absolute Interferometer".

5.SPEED AND ACCURACY

The measurement still takes about 0.2 seconds to complete, but unlike our competitors "fast" ADM's there is no loss in accuracy due to the reflector moving during this process. If a "fast" ADM is able to measure at 10,000 measurements per second, then it has a 100 microsecond integration time. If the reflector is moving during this time, and the system doesn't have a way to monitor that movement (as is done with the AIFM), then any movement during the integration has the potential to be applied to the uncertainty of the measurement. For example, let's use a reflector that is moving at a ½ meter per second during integration. If an ADM with a 100 microsecond integration time is used to measure it, then the following can be calculated: 500 mm/s * 0.0001 s/measurement = 0.05 mm/measurement. The uncertainty of the measurement could be as bad as the uncertainty of the ADM (10 µm) plus the uncertainty due to the movement (50 µm), making the total measurement uncertainty up to 60 µm. If the same process is done with the AIFM, the relative motion of the reflector is known during the complete measurement sequence, so even though it takes longer to integrate, the results are still within the uncertainty of the ADM (typically 5 µm). The other advantage is that the AIFM never uses just one single measurement in time. Since it always has the IFM as a reference, redundant sampling can be used to increase the accuracy of the measurement. This makes it impossible for a bad measurement to be fed to the IFM, which would make every following IFM measurement bad.

6.CONCLUSION

The AIFM combines the best of both worlds. It provides a leading edge solution to an age old problem, but does so using mature technology. The IFM and ADM core technologies have been used for more than a decade in our laser trackers around the world. These core technologies have been improved and combined to create what we have dubbed the "Absolute Interferometer" or AIFM, and represent the most accurate and stable dynamic distancing unit that we have ever created. The AIFM truly changes the way that laser trackers are used.

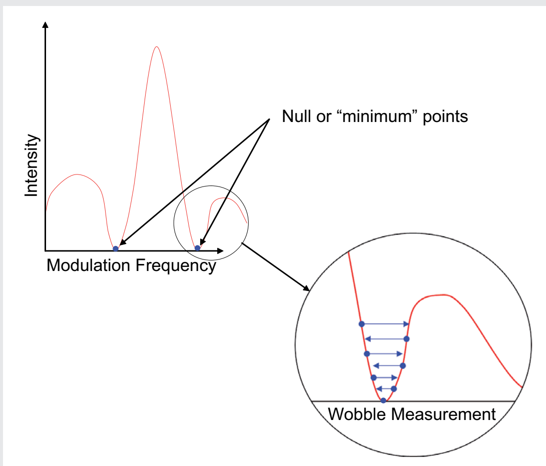
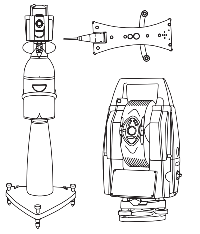
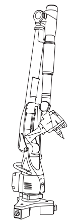


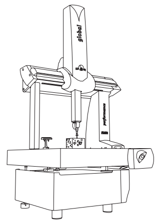
fig. 3



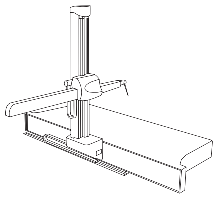
LASER TRACKERS & STATIONS



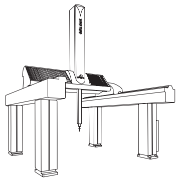
PORTABLE MEASURING ARMS



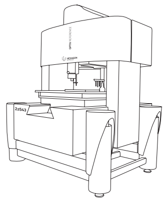
BRIDGE CMMS



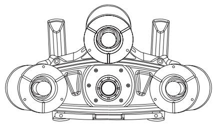
HORIZONTAL ARM CMMS



GANTRY CMMS



MULTISENSOR & OPTICAL SYSTEMS



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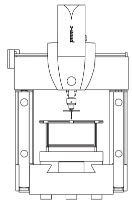
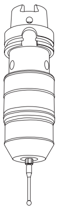
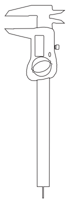


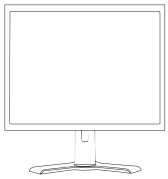
ULTRA HIGH ACCURACY CMMS



SENSORS



PRECISION MEASURING INSTRUMENTS



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