

AN INNOVATIVE NON-CONTACT SURFACE MEASUREMENT SOLUTION FOR ASPHERE, DEEP PARABOLIC, AND OGIVE GEOMETRIES

Scott Bambrick¹, Michael Bechtold¹, David Mohring¹, and Joe Meisenzahl¹
¹OptiPro Systems
6368 Dean Parkway, Ontario, NY 14519

INTRODUCTION

OptiPro Systems is developing a non-contact measurement system using state of the art motion control and calibration techniques while minimizing the axes of motion during the measurement and integrating a high accuracy non-contact probe. The goal is to precisely scan concave and convex surfaces of aspheric, deep parabolic, and ogive shapes without the limitations associated with other measurement methods. The metrology systems will use two different computer controlled slicing techniques to create a single line scan and complete a topographical surface map of the surface form and also take surface roughness measurements above 30 nm.

CONCEPT

The concept behind this metrology system was primarily centered around measuring the ogive shape shown in *FIGURE 1* with the minimal axes in motion necessary.

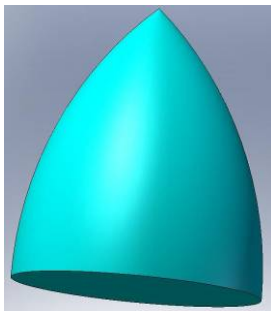


FIGURE 1. Tangent ogive shape.

The ogive shape lends itself quite well to this approach since it can be constructed by removing sections of a sphere. For this reason it is possible to measure the shape using a similar motion path to one that would be used for spherical measurements.

Our measurement system concept consists of a granite base for system and thermal stability. Attached to this base are the two primary axis of motion, the B and C rotary axes. Motion control

and repeatability of these axis will be the most critical as these axis will be conducting the majority of the motion during measurement. In addition, there will also be linear axes in the Z and X direction. For the ogive shape these axes will only be necessary for positioning of the measurement arm but for aspheric and deep parabolic shapes these axis will be in motion during the measurement process. *FIGURE 2* shows the CAD drawing of our measurement concept with the axes labeled appropriately.

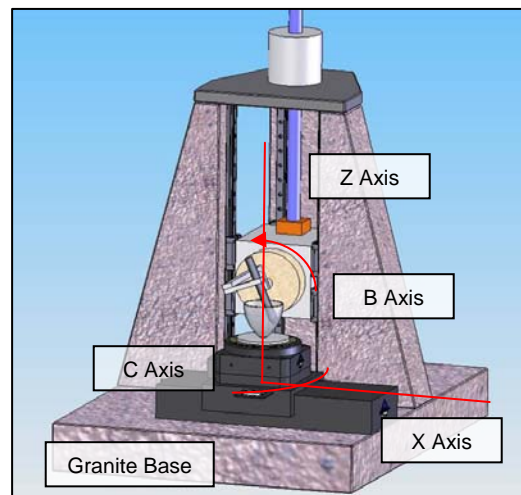


FIGURE 2. Concept metrology system with axes labeled.

Attached to the B axis is a non-contact collimated white light pen. This pen is capable of measuring with a resolution of 10 nm. We are currently looking to incorporate a pen capable of measuring the thickness of the surface at the same time as it measures the outside surface. This would provide many advantages over the white light pen since it would no longer be necessary to re-block the part in order to measure the inside surface. This is important since it would no longer be critical to compensate for errors associated with the blocking of the part in order to generate a transmitted wave front image.

The measurement for the axis symmetric parts will be conducted using two different techniques. The first technique, a B axis sweep, will rotate the B axis (Optical Pen) across the specified range of measurement. Once this motion is completed it will index/rotate the C axis (Work piece) over for the next slice of data. Once the surface scan is completed all of the data will be compiled and fed into the data processing software.

The second measurement technique is similar to the first technique except that the C axis is the primary axis of motion and sweeps across the part. The B axis then becomes the indexing axis. As with the first method, the data is then fed into the data processing software when completed.

Each of these techniques has advantages from a mechanical, motion control, and compensation perspectives and each can be used to achieve the desired characteristics.

ERROR BUDGET

A preliminary error budget was conducted to determine some of the main sources of mechanical motion errors that we will have to consider. The motions and the corresponding errors that they would produce were determined for the B, C, X, and Z axis. *FIGURE 3* shows a representative error budget diagram for the side from Z axis straightness, and Z axis pitch and yaw.

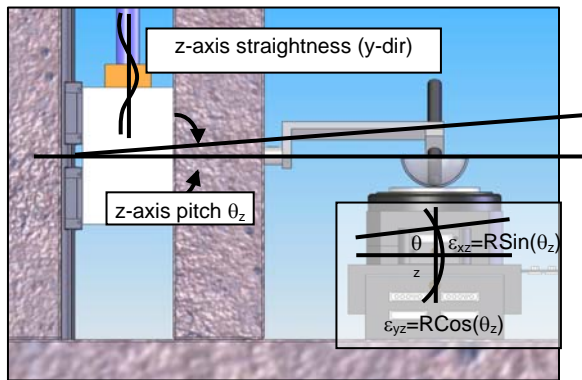


FIGURE 3. Z axis alignment errors and the corresponding positional alignment errors.

Each axis will need to be considered for the final error budget analysis and the total sum of errors will be considered to determine the capability of the system configuration.

BREADBOARD SYSTEM

A lower cost “breadboard” version of the machine was constructed to demonstrate the feasibility of this measurement system. This breadboard system will also be used to determine which avenues will need to be considered in order to improve the design and component selection.

In order to keep the cost of the breadboard system down an older Bridgeport milling machine was converted so that it could be used as the base of the metrology system. This base has many disadvantages when compared with the concept base. The foremost of which is the dove-tail way locking system for the Z axis. This caused the machine to drop over the course of a run and resulted in a 1-3 micron drop over a measurement scan. In addition, the X axis and Z axis were not computer controlled. This caused additional difficulty in tramping the part to measure into the correct position. For the B axis Professional Instruments loaned OptiPro Systems a high precision air bearing. Since this axis is critical to the measurement capability of the machine any rotary axis that was used would need to be very precise which is why the Professional Instruments bearing was a perfect fit. For the C axis a custom precision ball bearing rotary axis manufactured by AeroTech was used. *FIGURE 4* shows the completely assembled breadboard machine.

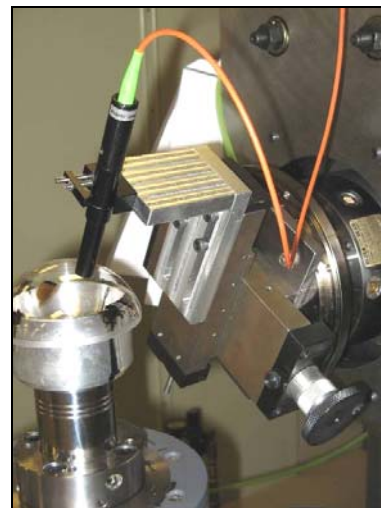


FIGURE 4. Assembled breadboard measurement device scanning a polished hemisphere.

BREADBOARD RESULTS

In order to properly align the part with respect to the B axis a method of tramping was developed. This method would move the B axis and scan across the top slice of the part. The measurement pen data was then used to diagnose the misalignment in the Z and X axis. The axes were then moved the appropriate direction and the process was repeated until the desired alignment was achieved.

Initial testing of the measurement capabilities of the breadboard system were conducting using a 1" gauge sphere and a near hemispheric sapphire dome. The dome was finished with an astigmatic defect that provided a measurable feature. Scans were taken with both the C axis and B axis sweeping techniques and the results were compared with each other.

The measurement of the 1" sphere was considered first. This known reference surface would provide knowledge about the mechanical motion errors in the system and would help to develop techniques to deal with these errors. The uncompensated scan from a B axis sweep is shown in *FIGURE 5*

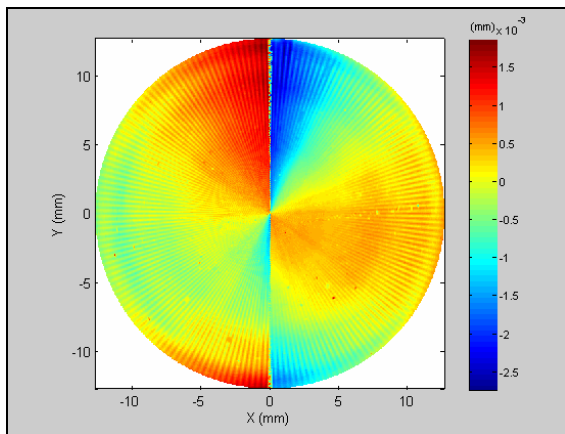


FIGURE 5. Uncompensated spherical deviation data from B axis sweep.

This data shows a combination of alignment errors that will need to be corrected for in order for meaningful results to be obtained from the metrology system.

The B axis sweep data was then processed to remove the X axis alignment, Radial alignment, and Z axis drop errors. *FIGURE 6* shows the compensated spherical form deviation data for the 1" gauge sphere.

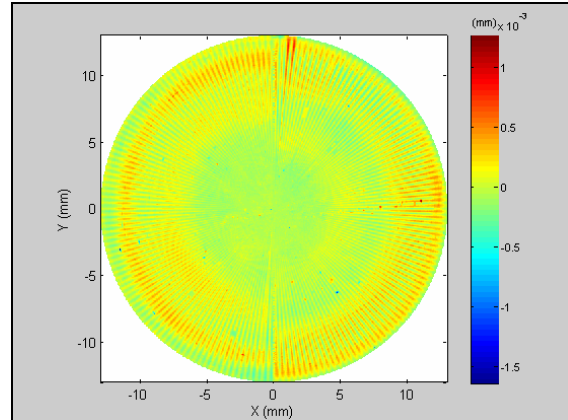


FIGURE 6. Compensated spherical deviation of 1" gauge sphere.

Once these errors were removed the form error was five times less than the uncompensated data. It is still possible to see striations in the scan associated with the mounting of the white light pen to the B axis. It was determined that the C axis sweep measurement technique did not suffer from the same difficulties with the mounting of the measurement pen and the slight shift associated with that motion.

From this data we were also able to determine the amount of time necessary to allow the Bridgeport Z axis settle to its final resting height. This measurement wait time was then applied to all of the scans so that all of the results would be consistent and accurate. This method of the system error mapping for the extreme breadboard conditions was very useful in the development of the conceptual design.

After the techniques for measuring the gauge sphere were developed a near hemispheric sapphire dome was measured. This dome contained an astigmatic form defect that would allow for easy characterization of the metrology system's capability to measure imperfections. The results from these measurements, shown in *FIGURE 7*, were generated using a C axis sweep and show the spherical deviation of the part.

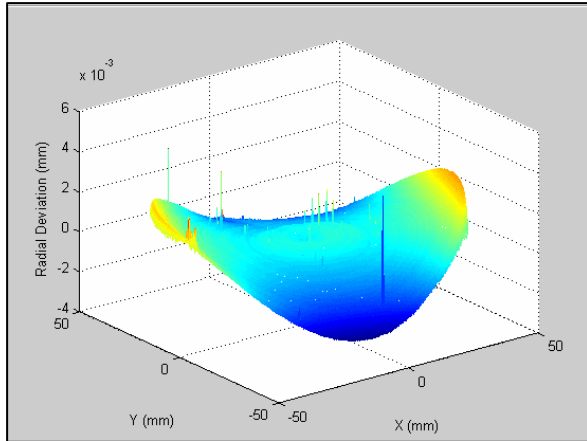


FIGURE 7. Spherical deviation of near hemispherical sapphire dome.

This plot shows the “potato chip” that is characteristic of an astigmatic error. The total peak to valley surface deviation was found to be 4.5 μm .

The results obtained from our breadboard metrology system were compared to results obtained from a QED stitching interferometer. The data was rotated so that the orientation was the same using a reference placed on the part. **FIGURE 8** shows a comparison of our results to the stitching interferometer results. The results from our measurements are very close to those obtained using the stitching interferometer and are within 0.5 μm of the stitching results.

FUTURE WORK

Although initial results correlate closely with the results obtained with other qualified metrology systems there is still work that needs to be conducted to improve the motion of the axes, and measurement capabilities. The Bridgeport base of the breadboard system was proven to introduce a large number of measurement errors to the system. This has shown that it will be

necessary to provide the production metrology system with a solid and stable base.

In addition, the production machine will need to be vibration isolated using an air table. The breadboard version was highly susceptible to any vibration in the measurement floor from other machinery. These vibrations would cause non-repeatable errors in the measurements and would negatively impact the accuracy of a set of data.

In the production system OptiPro will be using air bearing spindles. The Professional Instruments air bearing spindle greatly reduced non-repeatable errors. System error mapping only works with repeatable errors or errors that can be directly related to measurable system parameters (positions, weight, and temperature). In addition to the air bearing spindles, linear motion air bearings will be investigated to determine if their use is necessary.

Perhaps the most necessary improvement in the production version of the machine from the standpoint of ease of use will be the incorporation computer controlled motion to the X, and Z axes. This would allow for an automated part alignment process to be created as well as allow for the measurement of aspheric shapes.

It will also be need to be determined if the use of volumetric style compensation tables will be required in order to accurately account for the axis of motion errors. Although this will not be difficult when considering shapes that can be constructed from spheres it may become time consuming and difficult if the Z, X, and C axis are all in motion at the same time and a complete 4 dimensional error compensation table must be produced.

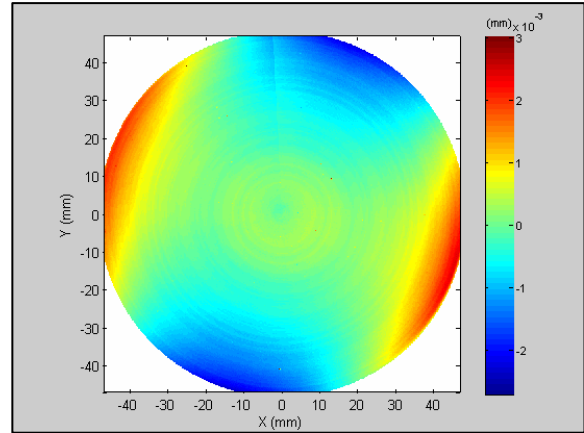
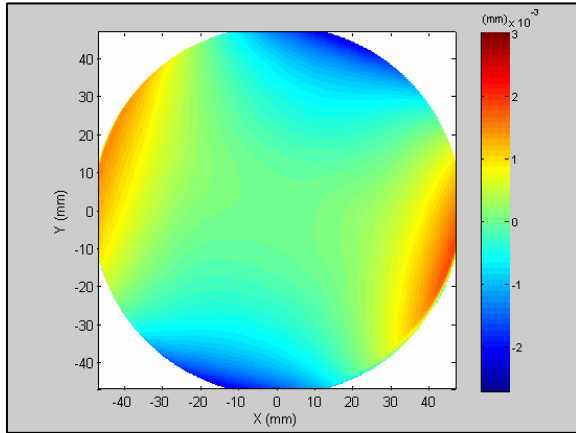


FIGURE 8. Comparison of spherical deviation data from the breadboard measurement system (left) and the stitching interferometer (right).