QUALIFICATION AND PERFORMANCE ANALYSIS OF AN INTERFEROMETRIC SENSOR

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Background: On 16 December 1991 testing of the MIST ADR was performed at Rank Taylor Hobson, in Keene New Hampshire. RTH has agreed to support WJSA in development of MIST in the expectation that the gages developed through this effort will result in enhancement of their products. No concessions or promises have been made to RTH by WJSA, though they have been extremely generous with their time in reviewing gaging concepts and applications.

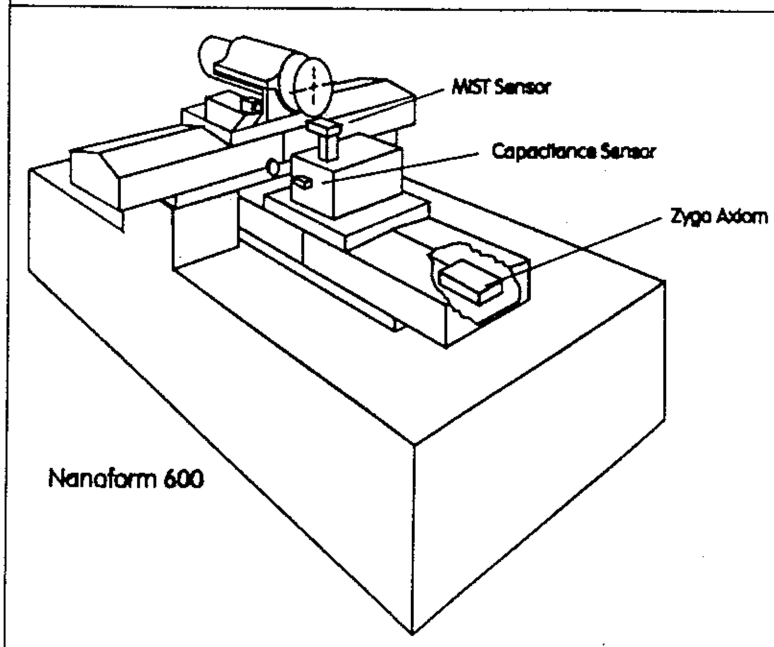
Setup: The machine used as a testbed was the Nanoform 600, RTH's premier and newest SPDT lathe. The machine utilizes hydrostatic bearings and is close loop position controlled using a Zygo Axiom heterodyne interferometer to measure linear position. This measurement system is reputed to exhibit accuracies of as good as 2.5 nanometers in this application.

Figure 1 shows the location of the MIST ADR on the Nanoform 600 as well as the position of the Zygo system and a third displacement measurement system (a capacitance probe) which was also installed. Note that there are approximately 18 inches separating the axis on which the Zygo system measures linear position and the machine workpiece spindle. Since position control is closed about the Zygo, variations in spacing at the workpiece spindle (which the MIST ADR was set up near) can occur, particularly if the temperature varies. The capacitance gage was much closer to the ADR, only about 6-8 inches away.

Tests Performed: A series of tests were performed. These consisted of a Drift Test, Incremental Positioning Tests, Full Range Test, and a Repeat Initial Position test. The intent was to demonstrate that the MIST ADR agreed with the Zygo System to better than 10 nanometers, was capable of stable operation over extended periods of time, and could reproduce a specific initial position even after large excursions outside the range of the sensor when returned to within range.

Data: Data was recorded directly on the MIST computer for the ADR position and the temperature at the ADR sensor (as sensed by a 0.01 degree C resolution thermistor.) A second com-

Figure 1: Configuration of Sensor on Nanoform 600



puter recorded the Zygo Position data. The clocks of the two computers were synchronized and all measurements made on a common time base for later comparison. The output of the capacitance gage was recorded on a strip recorder and later digitized by hand and input to support data analysis. Additional observation of the temperature of the air shower which surrounded the Nanoform 600 was made via the RTH thermal control system, but was not recorded. Full range observed was on the order of 0.3 degrees C during any of the test runs.

Analysis: The following sequential analysis was performed.

Step Test: During this test linear position was varied by 10 nanometers per step. Each position was maintained for 30 seconds during which data was acquired by all systems. Six steps were made in one direction and then retraced back to the original position. Figure 2 illustrates the position recorded by each sensor.

Figure 2: Position vs Time for All Sensors

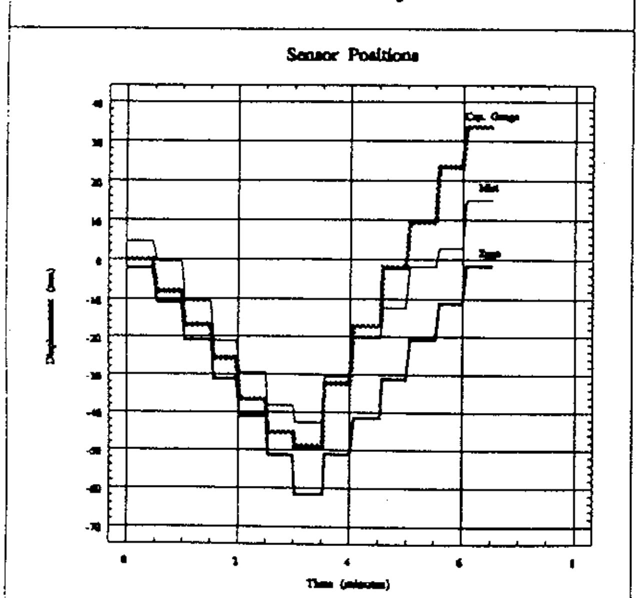


Figure 3 illustrates the difference between each of the sensors. Maximum deviation between the MIST sensor and the Zygo was approximately 12 nm forgiving initial offset. The Zygo to capacitance gage difference was approximately 34 nm. Note that the maximum difference between the MIST and Zygo systems is smaller than the accuracy specified by RTH for positioning of the Nanoform 600 by RTH.

Figure 3: Differences Between Sensors vs Time

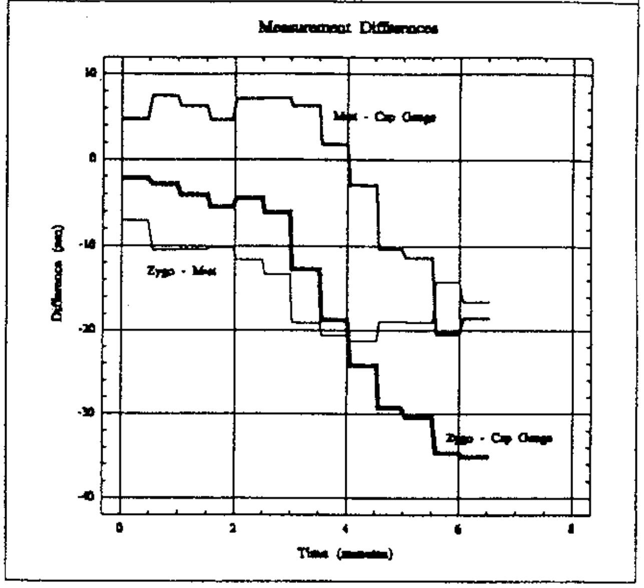


Figure 4 shows the correlation between the MIST ADR and the Zygo gage. The correlation Coefficient is high, 0.973, showing excellent performance of the MIST sensor.

Figure 4 Correlation Between MIST Sensor & Zygo Measurements

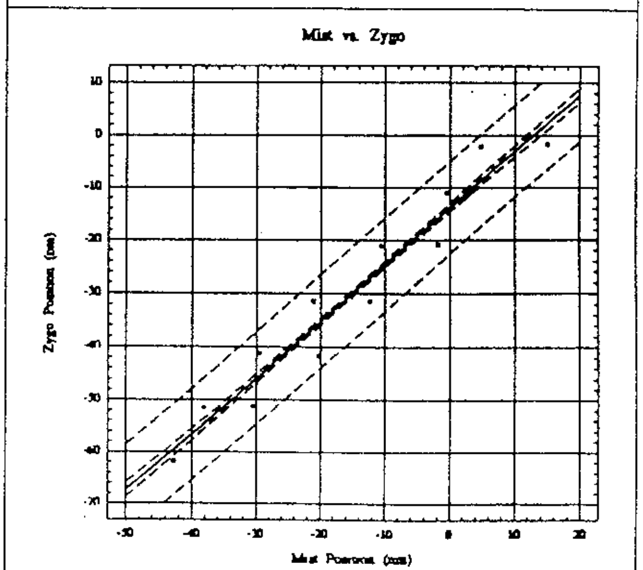


Figure 5 shows correlation between the Zygo and the capacitance gage. The correlation coefficient of 0.868 shows a lower degree of correlation than between the ADR and the Zygo.

Figure 5: Correlation Between Cap Gage & Zygo Measurements

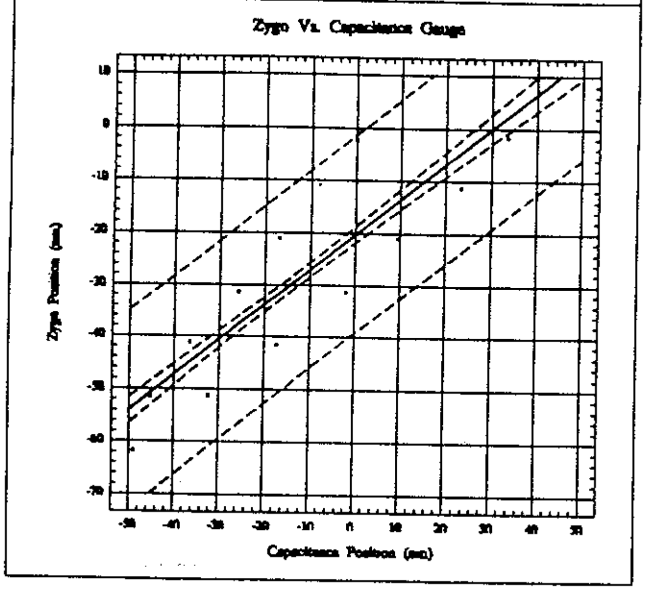


Figure 6 illustrates the correlation between the MIST and the capacitance sensor.

Figure 6: Correlation Between MIST Sensor & Cap Gage Msmts

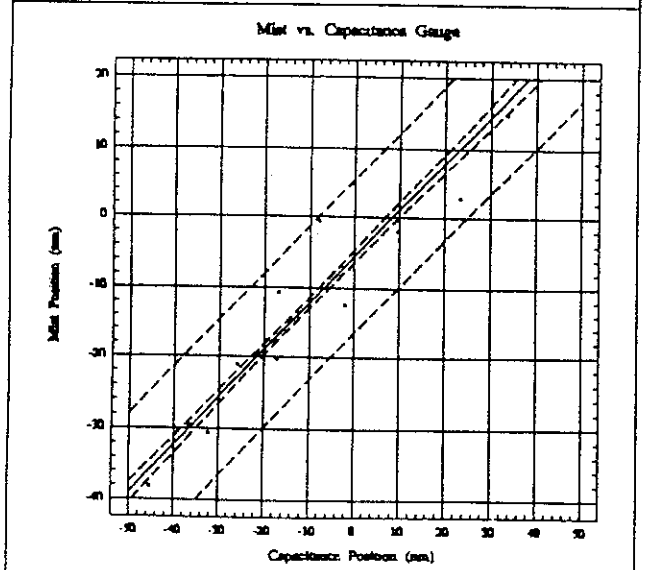


Figure 7 is a plot of the temperature at the MIST sensor during the test period. Multiple readings were averaged for each time period. The magnitude of the temperature variation during the entire test was approximately 0.7 degrees C.

Figure 7: Temperature Vs Time During Test

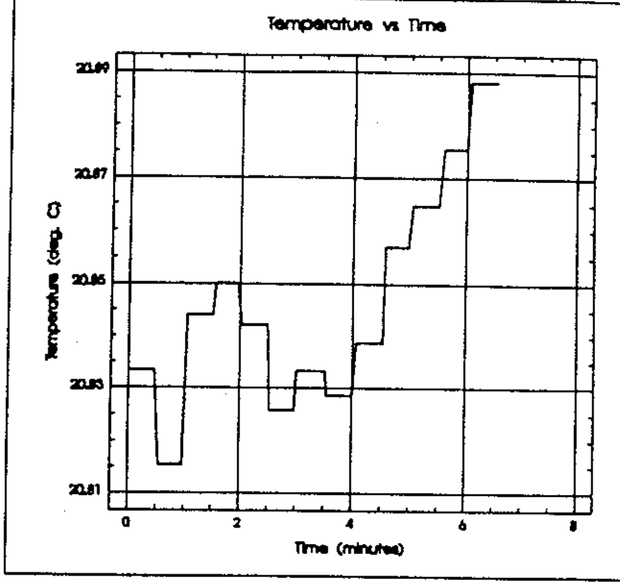


Figure 8 illustrates the correlation of the difference between the MIST sensor and the Zygo with temperature. The relatively low correlation (0.208) shows that the MIST sensor is relatively little affected by temperature.

Figure 8: Correlation Of MIST Difference To Temperature

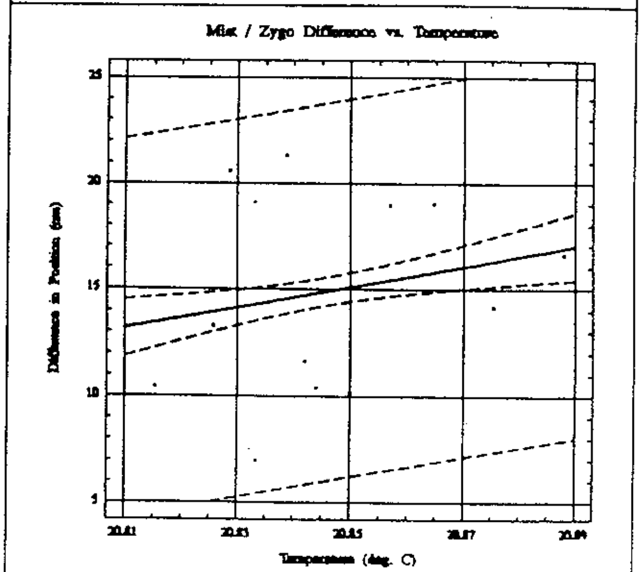
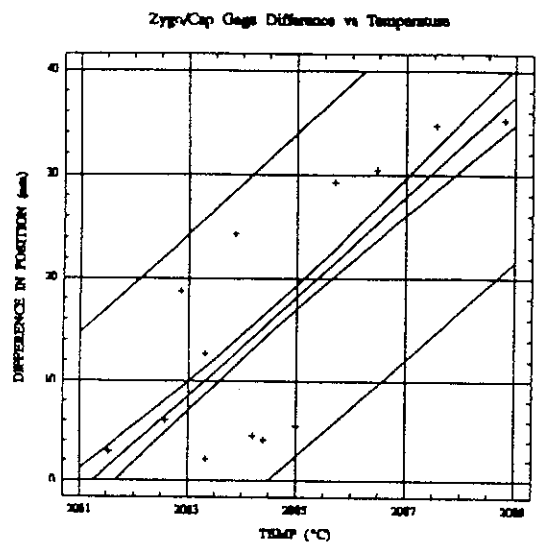


Figure 9 shows the much higher degree of correlation between the difference between the Zygo and the capacitance gage to temperature.

Figure 9: Correlation Of Cap Gage Difference To Temperature



Full Range Test: In this test the position was changed incrementally in 500 nm steps to explore linearity of the MIST sensor over it's full range Figure 10). As can be seen in Figure 11, the difference between the MIST ADR readings and the Zygo appear functional in nature and can be shown to have a functional dependence as shown by the 4th order polynomial fit.

Figure 10: MIST & Zygo Position Over 6 Microns

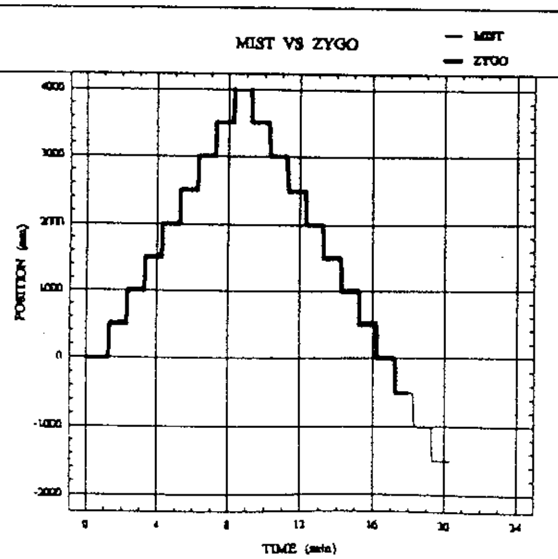
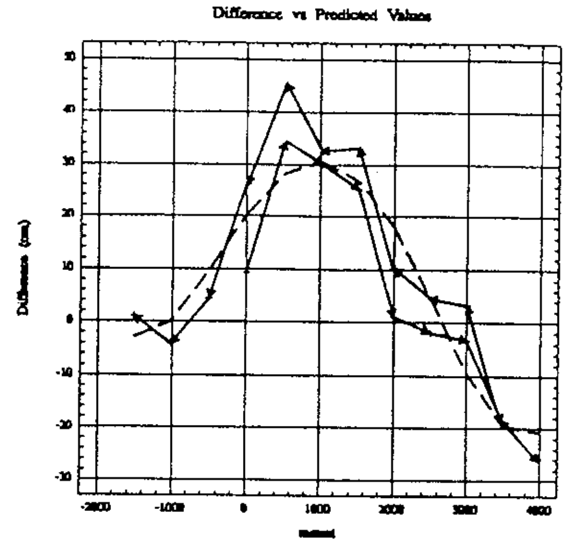
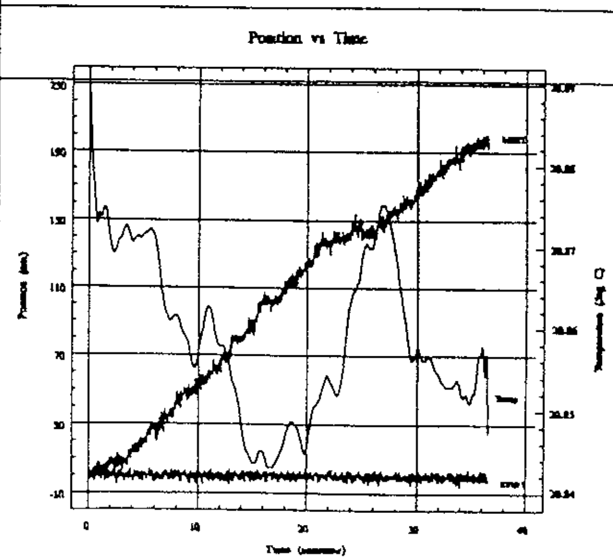


Figure 11: MIST/Zygo Difference Vs Position



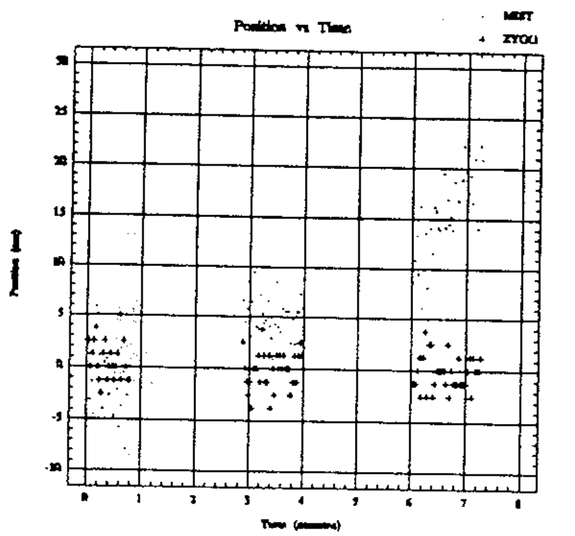
Drift Test: In this experiment, position remained steady in closed loop fashion about the Zygo Axiom. MIST position was monitored, and as can be seen in Figure 12, the MIST sensor shows a nearly linear drift over 30 minutes. the monotonic nature of change of MIST sensed position is in contrast to the temperature sensed at the MIST sensor by the thermistor, which rose and fell several times during the test.

Figure 12: Position & Temperature Vs Time



Repeatability of Position Test: An initial position was established and maintained within the MIST capture range for several minutes. Subsequently, the carriage was translated far beyond the capture range of the MIST sensor and then returned. The object was to determine whether the MIST sensor would return to the same position as the Zygo indicated and hence determine it's capability as an initialization sensor. Figure 13 shows the substantial drift which occurred during the replications of this test.

Figure 13: Errors In Achieving Repeated Initial Positioning



CONCLUSIONS: The following are our conclusions on each of the tests performed.

Step Test: The high degree of correlation between the MIST sensor and the Zygo positions illustrates that resolution and accuracy of the MIST sensor meet our initial objectives of on the order of 10 nanometers. The performance of the MIST sensor clearly exceeds that of the commercially available capacitance sensor, which showed a high degree of dependence on temperature. The MIST ADR was little affected by temperature, a fact which we attribute to the use of low CTE components in it's construction.

Full Range Test: This test showed a functional error in MIST ADR position measurement over it's full operating range of about 10 microns. We believe that this is due to optical aberrations inherent to the beamsplitter cube and mirrors and the extrapolation of fringe position which is used to make the measurement. We believe that we have several viable alternatives which will substantially reduce this error. The error is repeatable, and hence, even if no other approach resolved it, it could be accommodated through calibration.

Drift Test: The constant near linear drift of the MIST sensor is hypothetically attributed to bulk thermal drift of the Nanoform 600 during the course of the test. While the temperature sensed at the MIST sensor had several inflection points, it is more reasonable for the bulk temperature of the Nanoform machine to vary monotonically over the course of the test due to it's substantial thermal inertia. The way we would propose to resolve this problem is to redo this test with the Zygo and the MIST sensor measuring very nearly the same coaxial space, rather than 18 inches apart.

Repeatability of Position Test: This test also showed the same linear drift as the Drift Test. We believe that this test is flawed for the same reason as that one. We propose to establish a low CTE test fixture which will provide a highly stable geometry to test drift and repeat position against.

SUMMARY: In summary, the testing of the MIST ADR at Rank Taylor Hobson showed that our sensor has genuine promise as a competitor to current, commercially available gaging systems. It also showed that a more dedicated test system or modification to machine tool brassboards will be necessary to support efficient development and refinement of the MIST sensor. The basic objectives of our IR & D program have been met, though shortfalls in stability and full range linearity were observed. The nature of the errors observed are an excellent match to the hypotheses we have developed to explain them. Consequently, we are encouraged by the results of this initial test program and MIST will continue to be refined and developed.