INTRODUCTION

Hybrid (or Multi-sensor) Coordinate Measuring Machines (CMMs) belong to new generation of CMMs, gaining popularity in the current world market due to the flexibility of changing the sensing device without having to re-establish the part coordinate system. The distinction we make between Hybrid and conventional CMMs – which permit multiple sensors to be swapped on and off the CMM ram – is that the different sensors in a Hybrid system have different metrology loops. There is no standard documented for the performance of such multi-sensor CMMs. The assessment of the errors or uncertainty present in the use of each probing system may be done in a manner similar to that described in the existing B89.4.1 standard (multi-tip), but the quantification of these errors has not been studied. The primary focus of our work is a better understanding of the uncertainty introduced when measuring the same work piece with different sensors, and the development of artifacts and procedures to document this uncertainty.

In this paper we report tests conducted on a Hybrid CMM at UNC Charlotte with the intent of exposing errors in the touch and vision probes and their relative offsets. We also discuss some experiments using an Opto-Mechanical hole plate, conducted for comparing machine performance with the different sensors. One series of experiments performed allows us to quantify the errors over a large fraction of the machine volume, while others examine how machine errors can change over time.

PREVIOUS WORK

Measurements on a Werth hybrid CMM at UNC Charlotte have included experiments to expose sensor offsets and reversal measurements on an "opto-mechanical hole plate" [1]. We extend this work to experiments that are designed to reveal errors in the machine volume for different sensors. This paper presents the results of drift experiments with both the sensors, and examines machine geometry errors both locally and through the whole machine volume.

DRIFT TESTS

This test is much like the one described in the existing B 89.4.1 standard [2]; it is especially pertinent for machines that use a light source for measuring with a vision probe, as self-heating of the machine can result in large geometric deformations in the metrology loop. We will discuss two long-term tests in this section. The first is a simple repeat measurement of single feature with each of the two sensors, while the second test involves tracking the apparent machine geometry errors (in this case, xy-squareness).

For these tests we use an Opto-mechanical hole plate, designed and manufactured by Centre for Geometrical Metrology at Technical University of Denmark [1]. This artifact is shown in Figure 2. In the first test, a single hole is measured alternately by touch and vision sensors, and the variation in location of the hole is tracked. As seen in Figure 1, the drift over an 8-hour test can be significant. As this experiment was conducted in a temperature controlled laboratory, the variations observed are not due to change in lab environment.
The second drift test used location data from all 25 of the holes on the holeplate. These locations were compared to a set of reference data obtained by measuring the holeplate on the Leitz PMM654 in several orientations. Averaging was used to eliminate the squareness errors in the data obtained from the PMM. The data obtained from the Hybrid CMM were compared to the reference values in a manner similar to that used by Hocken and Borchardt [5]. In our calculations, \((x_1,y_1)\) are the reference coordinates, and \((x_2,y_2)\) are the coordinates from the measuring machine under test. A shift of \((\varepsilon_x, \varepsilon_y)\) and rotation by \(\beta\) correspond to a rigid motion of the holeplate, while the squareness error \(\alpha\) and scale errors \(\gamma_x\) and \(\gamma_y\) are machine errors. The machine errors calculated are those which give the minimum sum-of-squares distances between the measured and reference coordinates. Equation (1) is used to find these shifts and errors.

\[
\begin{bmatrix}
\sum y_1^2 & -\sum y_2^2 & -\sum x_1y_2 & 0 & -\sum y_2 & 0 & \alpha \\
-\sum y_2^2 & \sum x_1^2 + \sum y_1^2 & \sum x_1y_2 & -\sum x_1^2y_2 & \sum x_2 & -\sum x_2 & \beta \\
-\sum x_1y_2 & \sum x_1y_2 & \sum x_2^2 & 0 & \sum x_2 & 0 & \gamma_x \\
0 & -\sum x_1y_2 & 0 & \sum y_2^2 & 0 & \sum y_2 & \gamma_y \\
-\sum y_2 & \sum y_2 & \sum x_2 & 0 & N & 0 & \varepsilon_x \\
0 & -\sum x_2 & 0 & \sum y_2 & 0 & N & \varepsilon_y \\
\end{bmatrix}
= \begin{bmatrix}
\sum (x_1y_2 - x_2y_1) \\
\sum (x_1y_2 - x_2y_1) \\
\sum (x_1^2y_2 - x_2^2y_2) \\
\sum (y_1y_2 - y_2^2) \\
\sum (x_1 - x_2) \\
\sum (y_1 - y_2) \\
\end{bmatrix}
\]

Note: In Equation (1) above, the summations are performed over the data from all 25 holes, and \(N\) in the matrix refers to the number of features being compared – in this case, 25.

This test was run for eight hours, alternately measuring the 25 holes with the touch and vision sensors. On average, a complete cycle for both sensors was started every 10 minutes. For each set of measurements, the parameters \(\alpha, \beta, \varepsilon_x, \varepsilon_y\), etc. were calculated. We then examined how these values changed over time, and plotted them individually. The plot in Figure 3 shows how the squareness values vary over the duration of the test for the measurements with each sensor. The original data was a bit noisy, so the plot shown here reflects the moving average of six runs over time.

Figure 1: Vision Probe (left) and Touch Probe (right) drift in x. The horizontal line spacing is 1µm.

Figure 2: Opto-Mechanical Hole Plate
GRID TEST

In the next test we again use the holeplate reference coordinates obtained by reversal measurements using our Leitz PMM. To obtain a better picture of the errors throughout the entire measuring range of the Hybrid CMM, the plate was measured in four locations which overlapped by a single row of holes [3]. The results plotted in Figures 4 and 5 show an interesting difference between the vision and touch probes. The scale of the graph is as follows: the holes are spaced on nominal 20mm centers, so the five by five grid of holes cover an 80mm by 80mm area. Since the four positions in which the hole plate artifact was measured overlapped by a row of holes, the overall area spanned by these tests is 160mm by 160mm. The errors in measurement (relative to the reference values), are shown by the whiskers at each grid point and are magnified by 1000 times, so a whisker that reaches halfway across one grid spacing has a magnitude of 10µm.

Figure 3: Apparent Squareness in XY, reported by sensor used.

Figure 4: Vision Sensor Data in D0 position

Figure 5: Touch Probe Data in D0 position
There is a systematic pattern in the errors for each sensor: as we increase in the y direction the x-error increases. For the vision data the y-increase corresponds to a positive x error, and for the touch data the y-increase corresponds to a negative x error. The conclusion we might draw from this is that the xy-squareness of the machine is different, depending on the sensor used. As a common xy-stage is used for both sets of measurements, it is possible that the geometric relationship between each of the two sensor z-axes and the plane defined by the x-y stage is different.

CONCLUSIONS

Multisensor CMMs are gaining importance in many industrial applications because of the flexibility in quickly joining the data obtained from touch and vision sensor. There are currently no standards for such CMMs. In this paper we have claimed that while standard CMM performance tests (such as a drift test or multi-tip test) described in B89.4.1 can serve as a starting point, users of this type of CMM will need additional information to fully understand the errors in their machine. A major challenge remains in incorporating the data obtained from the measurements we've described into diagnostic tools that will characterize the machine errors that occur during the tests.

FUTURE WORK

Future work will include measurements on a “Kite Square” artifact (shown in Figure 6) designed and manufactured at UNC Charlotte [4], which will help us in determining squareness between the z-axis and the xy-plane of the machine under test. It will also allow comparison with other Multi Sensor measuring machines. Ultimately, we wish to provide artifacts and procedures which will allow the estimation of the uncertainty of measurements that use both of the sensor systems. This will provide guidance for users of these Hybrid CMMs.

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REFERENCES