A Comparison of the Relative Uncertainties of a Single-axis Measuring Machine Fitted with Various Displacement Measuring Systems

S. J. Ramsdale Staff Metrology Engineer
AlliedSignal Aerospace, Kansas City Division
Kansas City, Missouri

ABSTRACT

This paper discusses an attempt to make a relative comparison of the performance of an ordinary supermicrometer retrofitted with several different displacement measuring systems. The methodology used is was a gage repeatability and reproducibility study, also known as a proficiency test. The environment, equipment, and operators were held constant in an experimental design that highlights the difference in capability of the various displacement measuring systems.

INTRODUCTION

Single axis measuring machines of various configurations are one of the most common types of gage measuring instruments. They range in capability from relatively simple micrometer head systems to expensive air-bearing based laser interferometer systems. The difficulty faced is in determining the improvement in performance of the various systems versus the cost.

As a representation of the cost versus capability equation, the study discussed in this paper compares the capability of a supermicrometer fitted with a micrometer drum, a digital rotary encoder, a laser interferometer, and a Laser Doppler Displacement Meter tm. The cost of these systems above the basic cost of the measuring machine range from a few thousand dollars to between fifteen and twenty thousand dollars.

This study was funded by the Department of Energy's Technology Transfer Program at the request of Dr. Charles Wang, President of Optodyne, Inc. , manufacturer of the Laser Doppler Displacement Meter tm(LDDMtm).

EQUIPMENT

The measuring machine used for this study was a Pratt & Whitney, Model B supermicrometer. This same machine was used to collect data for the micrometer drum, the laser interferometer, and the LDDM tm. The digital rotary encoder data was taken using a separate Model C Supermicrometer. For all tests, the tailstock of the supermicrometer was locked down and the anvils lapped flat and parallel to less than 10 Micro inches.

The micrometer drum was graduated in increments of 0.0001", with no vernier scale. Using magnification, it seemed reasonable to divide each graduation into 4 parts, for an effective resolution of 25 μinches.

The digital encoder was factory fitted to a Model C Supermicrometer. The lead screw on this particular supermicrometer had just been replaced and adjustment was still in progress, but the data gathered proved to be typical of this quality of lead screw. The resolution of the readout was 10 μinches.

The laser interferometer and the LDDM™ were both retrofitted to the same supermicrometer and both had a resolution of 1 μinch.

EXPERIMENT BACKGROUND

All data was collected in the same location in an environmentally controlled laboratory. The air and artifact temperatures were monitored using a thermistor system certified to ± 0.03 C. The artifacts were placed on a soak plate during all tests and were held to a stability of less than 0.1 C for each test. The barometric pressure and humidity were also monitored using certified instruments.

No temperature compensation was made for data taken with the micrometer head and the digital encoder (it was assumed that the temperature of the artifact and the supermicrometer lead screw were nearly the same). For the laser interferometer system, compensation for the velocity of light in air calculated using Edlen's equation for the refractive index of air and the manufacturer's supplied equation for compensation factor number (these calculations were performed using AlliedSignal written software). The LDDM™ system was compensated using the manufacturer's software.

The artifact used as a reference was a set of cylindrical plug gages certified to a three sigma value of ± 5 μinches by the NIST. Sizes ranged from 0.100" to 1.000" nominal. The 0.500" gage was selected to be used as a master, and all other measurements referenced back to that gage. Cylindrical artifacts were used to eliminate operator variability in the wringing of gage blocks. The down side of using this particular set of artifacts was that they do not sample the lead screw for drunken threads, but it was felt that the primary purpose of comparing the two laser systems was best met with these artifacts.

Experience has shown us that one of the primary sources of drift in this type of instrument is thermal drift caused by the heating of the lead screw. The data collection was structured to identify this drift, if present, and allow it to be removed if appropriate. The data collection covered the range of one inch. Each data point was taken using the LVDT in the tailstock as a null meter. The data was taken by three operators with four runs each at eight sizes other than the 0.500 inch master.

The order of data collection for each run was as follows; Master, 0.1, 0.3, Master, 0.6, 0.9, Master, 1.0, 0.7, Master, 0.4, 0.2, and Master.

DATA ANALYSIS

The raw data was first converted to a measured value by adding the 'known' size of the master to all readings. The data was then analyzed by using the deviations of the measured values from the certified sizes of the artifacts. Two analyses were performed. The first was for the 'raw' measured deviations. For the second analysis, the drift in the zero (master) readings was assumed to be linear and was proportionally removed from the measured deviations. For each analysis, the measured deviations for the 0.5 inch master were not included.

The analysis of variance technique was used to analyze both the unadjusted and adjusted data sets. The variance components were computed as solutions to the equations of expected mean squares from the ANOVA table.

RESULTS

The results of the experiment are summarized in the following two tables. The first identifies the individual sources of variation and the magnitude of the variance caused by each source for both the unadjusted and adjusted data sets. The second tabulates the observed average deviations from certified size for each nominal for all systems.

The components of variance were not analyzed for the data taken from the micrometer head. The resolution of the readings was inadequate to recognize as significant the individual variance components. However, the observed averages of the nominals is listed.

Table 1 Components of Variance

(Note: Variance components are in μ''^2, Std. Dev are in μ'')

Response Source	Unadjusted data LDDM	Laser Interfer.	Digital Readout	Adjusted data LDDM	Laser Interfer.	Digital Readout
Nominals	2.43	4.26	57.05	2.97	7.27	53.98
Operators	2.46	1.52	9.11		0.36	4.15
OpxNom		1.95	19.41	4.17	1.37	24.24
Error	29.13	7.65	53.79	9.10	7.37	53.29
Total	34.02	15.49	139.36	16.24	16.38	135.66
S.D. w/o Nominals	5.62	3.33	9.07	3.64	3.02	9.04
Std. Dev.	5.83	3.92	11.80	4.03	4.05	11.65

The 'Source' column lists the source of variation in the study. The sources (beyond measurement repeats) observed in the study were Nominals and Operators. Table 1 lists the estimates of the variation as variance components.

The 'Nominals' source is the variation that represents the average deviations (or systematic errors) observed on the artifacts from their respective certified values. This variation is due to the differences of the actual sizes of the artifacts from their certified sizes and the systematic error (or bias) in the instrument at the artifact size. These two sources cannot be separated in this data. Table 2 lists the observed averages for each nominal. The listed average represents the true size of the artifact minus its certified value plus the systematic error in the measuring device (i.e. average reading plus bias).

The 'Operators' source is the variation in the overall average measurements for the operators. This variation may be due to technique, skill or other unidentified factor.

The 'OpxNom' source is the variation due to the interaction of operators and nominals. This source represents the inability of the operators to achieve the same measurements on the individual artifacts. That is, the operators do not repeat the individual artifact measurements in relatively the same pattern. For example, one operator may measure one artifact larger than the others while the other operators will measure that artifact lower than the others.

The 'Error' source is the variability of repeat measurements (within the same artifact and operator).

Table 2 Observed Averages for Each Nominal

	Unadjusted data				Adjusted data			
Nominal	LDDM	Laser Interfer	Digital Readout	Michead	LDDM	Laser Interfer	Digital Readout	Michead
Overall Mean	0.36	-0.67	-12.37	11.4	-1.06	-1.13	-11.22	11.4
0.1	-2.37	-3.12	-15.20	9.8	-2.98	-2.98	-14.65	9.8
0.2	4.05	-0.03	-12.70	4.8	2.27	-0.98	-11.04	4.8
0.3	-2.25	-2.75	-7.83	10.5	-3.48	-3.07	-6.73	10.5
0.4	-1.85	-3.68	-7.27	-16.4	-3.90	-5.23	-5.44	-16.4
0.6	0.13	-2.20	-21.87	11.5	-0.48	-1.82	-20.49	11.5
0.7	0.27	0.27	-23.9	8.6	-1.40	-0.57	-22.77	8.6
0.9	2.77	3.85	-3.90	32.8	0.68	3.93	-3.08	32.8
1.0	2.15	2.32	0.90	29.7	0.85	1.68	1.31	29.7

CONCLUSIONS

As a result of the experimental study, several conclusions may be arrived. Primarily, a comparison of the relative uncertainties may be performed. Using a coverage factor of two times the overall standard deviation for each system and adding in the overall mean of the data as a bias, the 'relative uncertainties' may be calculated. Although the numbers derived from this experiment are only valid for this particular type of data collection and the conditions of the experiment, the provide a way to measure the relative capabilities of each displacement measuring system. The relative uncertainties are as follows:

Table 3 Relative Uncertainties

System	Unadjusted Data			Adjusted Data		
	Standard Deviation (μ")	Bias (μ")	Relative Uncertainty (±μ")	Standard Deviation (μ")	Bias (μ")	Relative Uncertainty (±μ")
Micrometer Head	25*	11.4	***62***	25*	11.4	***62***
Digital Readout	11.80	12.38	***36.0***	11.65	11.22	***34.5***
Laser Interfer	3.92	0.67	***8.5***	4.05	1.13	***9.2***
LDDM	5.83	0.36	***12.0***	4.03	1.06	***9.1***

*Note: The resolution of the micrometer head was to large to truly identify the standard deviation of readings, so the resolution was used as an 'equivalent' standard deviation for the purpose of calculating 'relative' uncertainty.

Drift during data collection seemed only to be a problem for the LDDM. It had a noticeable improvement in uncertainty after the adjustment in the data. This was probably caused by the way the laser is mounted to the system.

Several other conclusions may be reached from the 'Components of Variance' table. For both laser systems, the primary source of variance was the repeatability. The nominals contributed to the overall variance, but the means of all the nominals were well within the uncertainty of their assigned values

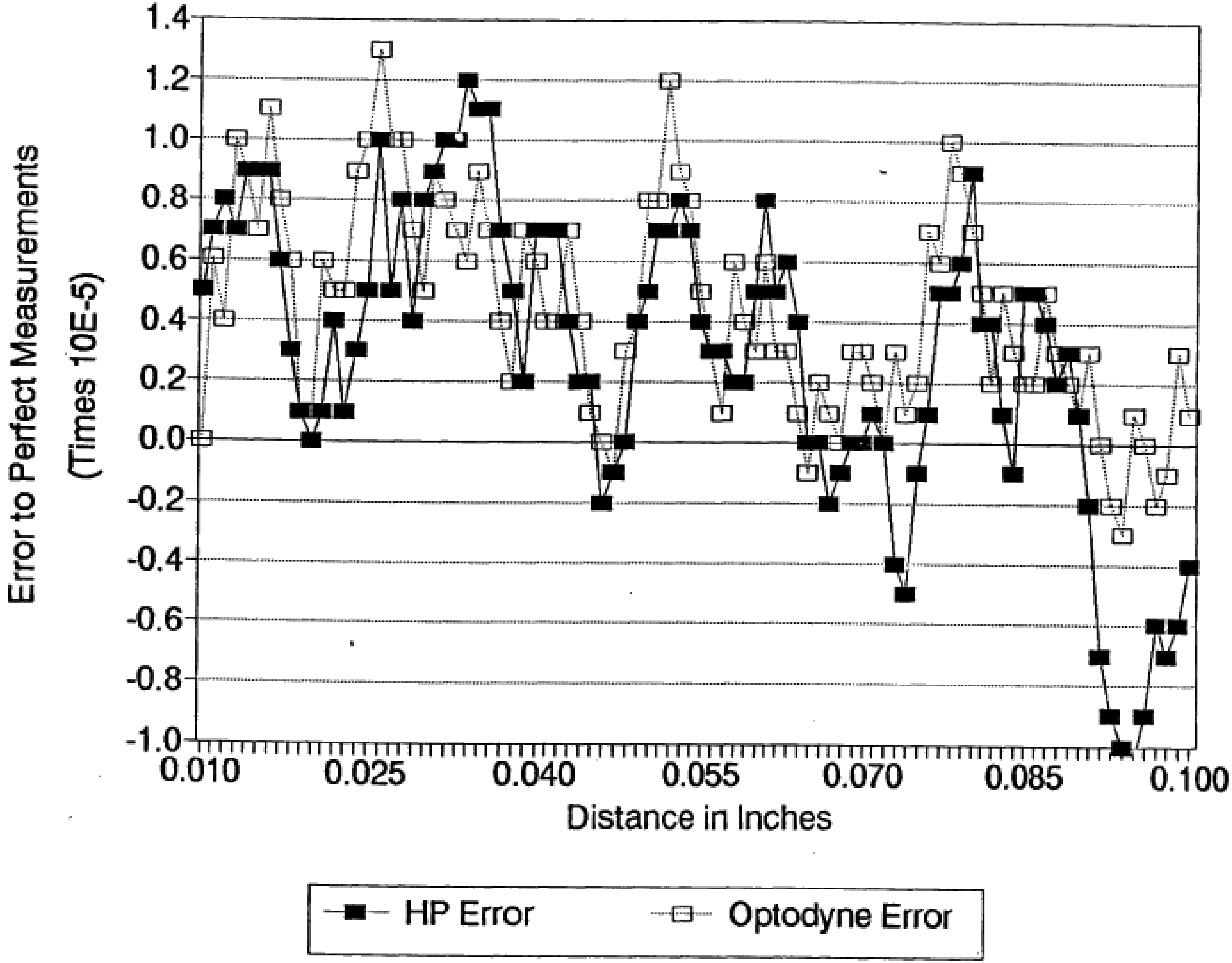
For the micrometer head and digital readout systems, repeatability was one of the two primary variability sources. Both systems had a large contribution to uncertainty by the nominal sizes, which is to be expected for a lead screw dependent device. Had the artifacts been chosen to test for drunkenness in the threads, this source of variability probably would have been larger. For the micrometer head readings in particular, the limiting factor was the resolution.

For all systems, the different operators were an insignificant source of variability. However, for operators with less experience and skill, this number would be appreciably higher.

Attached to this report are plots of all unadjusted and adjusted data for all the systems.

Test #1

Optodye and HP Laser Comparison



HP / LDDM drift over time