A NEW DESIGN FOR A THREE-DIMENSIONAL MEASUREMENT PROBE

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An Electronic Three-Dimensional measurement probe (E3D) was developed to be low cost, flexible, rugged, sensitive and accurate to ±0.25 µm in all three directions over its 250 µm measuring range. The unique diaphragm flexure design reduces the problem of force lobing while maintaining a low probing force of 20 mN/µm (2 gf/µm).

Design

E3D is a mechanically simple device designed for analog scanning. As shown in Figure 1, the sensors for the probe are three orthogonally mounted Linear Variable Differential Transformers (LVDT's) that provide frictionless measurement and are suited for sensing nanometer

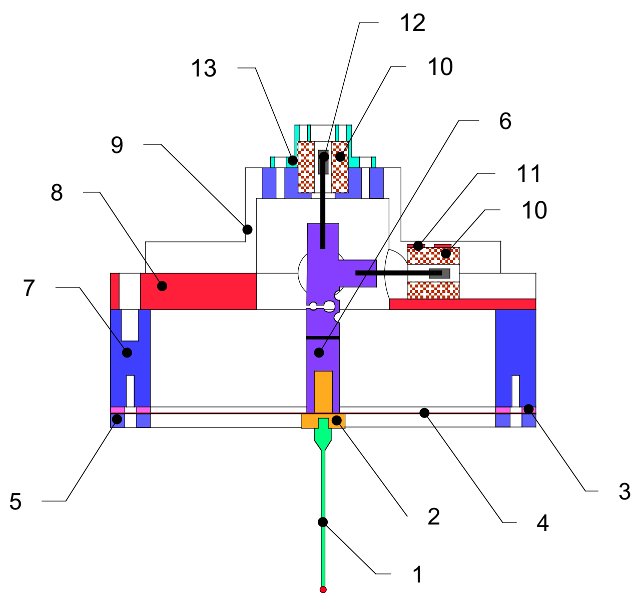

Figure 1 Schematic cross section of 3-D Probe 1. Stylus 2. Connecting Nut 3. Outer Clamping Spacer 4. Diphragm flexure 5.Middle Spacer 6. Triad 7. Shell 8. LVDT Support (bottom) 9. LVDT Support (top) 10. LVDT Coils 11. LVDT Cover (X Shown) 12. LVDT Core 13. LVDT Cover (Z)

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displacements. These sensors are rigidly coupled to a probe tip through a Triad and inconel beam. The system is free to rotate in two dimensions (X and Y) and translate in a third (Z) via a thin pretensioned diaphragm flexure. The diaphragm flexure and orthogonal arrangement of the three LVDT's allows independent sensing of the three directions. The diaphragm flexures also have the advantage that they can be easily substituted in different configurations to suit the measurement application.

Testing

The device has been tested on several standards: a flat plate, a step height standard and a gauge block to characterize its performance. Accuracy, repeatability and resolution all currently lie within the measurement noise band (±0.25 µm).

The most demanding of the tests - scanning a step height standard with multiple steps totalling 75 µm in height - revealed a measurement error of ±0.18 µm rms. All three axes were used over a substantial portion of their ranges in thesetests. Figure 2 shows the raw data output of each probe axis, specified as X', Y', and Z'. The raw data was then combined to evaluate the vertical displacements on the stepped sample and calculate the error in the measurement as shown in Figure 3.

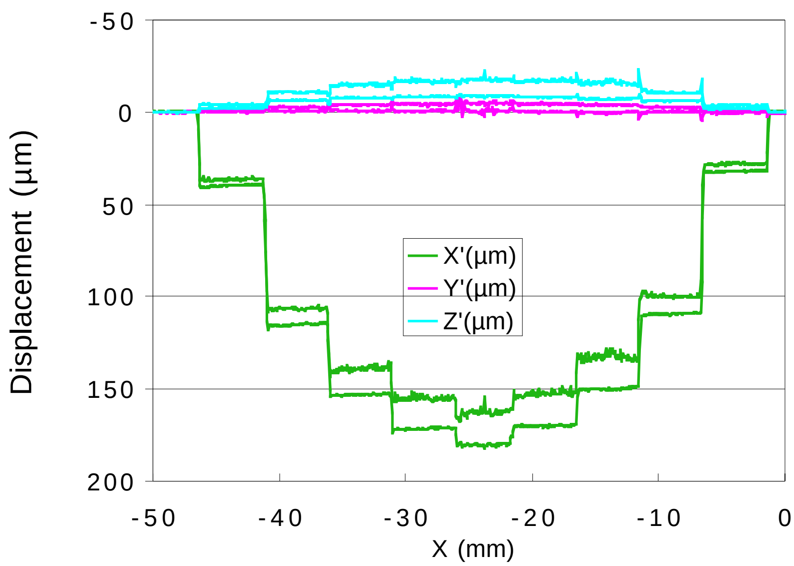

Figure 2 Raw Data obtained from the three axes of the probe upon measuring a stepped sample. The two traces for each axis represent a forward and reverse scan.

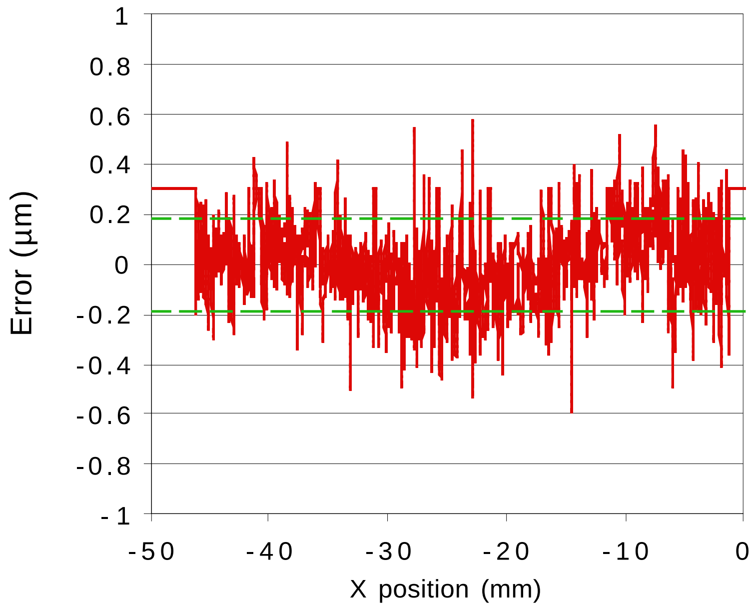

Figure 3 Error plot for stepped sample measurement. All three axes of the probe were used to generate a part profile, which was subsequently subtracted from the part's true profile to obtain the error in the Z- Direction. The dashed line indicate the RMS Value of 0.19 µm

Double Diaphragm Flexures

Since these tests were performed with the probe in the single-diaphragm configuration, force lobing presented complications. As can be seen in Figure 2, when the stylus was drawn across the surface of the sample, frictional forces caused large X- deflections since this measurement

axis was about ten times more compliant than the Z- direction. Oftentimes, the X-axis exceeded its measurement range, even for modest Z- deflections. This would certainly present significant difficulties for many types of measurements.

From the outset of this project, multiple diphragms were seen as an avenue for equalizing probing forces in different directions. The flexure design evolved through several configurations: from a machined aluminum diphragm, to one of steel and finally to a self-contained, pretensioned membrane. To eliminate the need for a tensioning mechanism on the probe, the flexure was pretensioned by soldering a 25 µm (.001") brass diaphragm to a copper ring. The difference in Coefficient of Thermal Expansion (CTE) between Copper (17 ppm/°C) and brass (20 ppm/°C) causes a strain on the diaphragm, pretensioning it. This flexure design allows a wide range probing forces to be obtained as well as the use of multiple flexures in a stacked configuration.

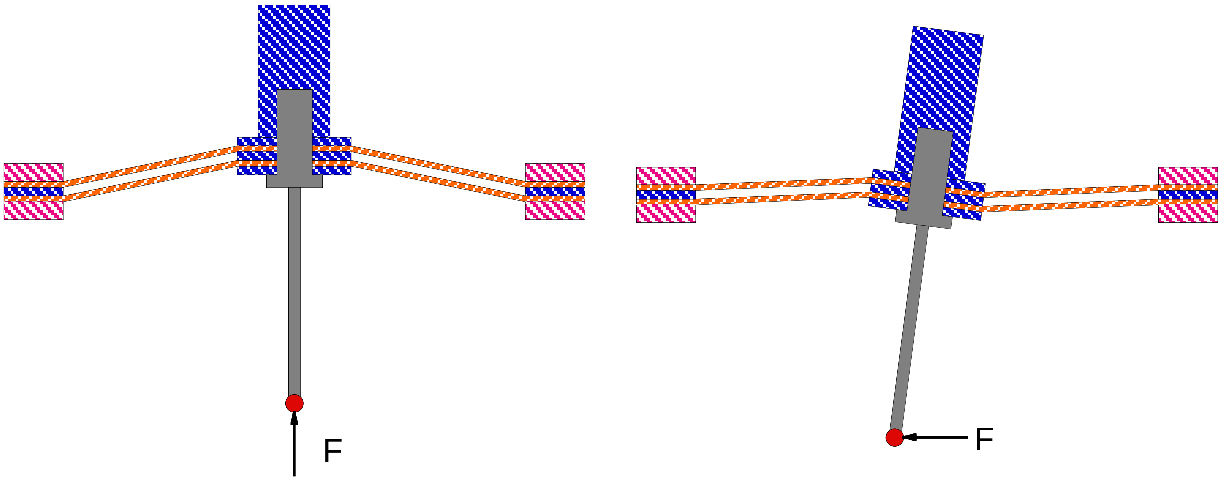

Figure 4 Schematic cross section of probe with double diaphragm. (a) shows deflection in the axial (Z') direction and (b) shows deflection in the radial (X' or Y') direction.

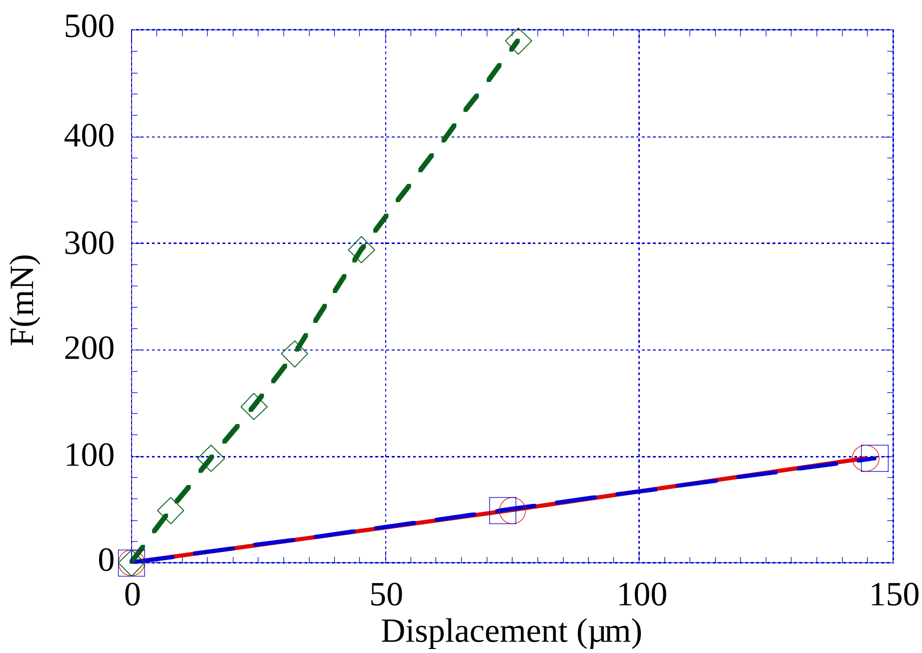

Figure 5 Force/Displacement curves with single. G, E, and A represent the X', Y' and Z' directions, respectively. The slopes of these curves represent the stiffness in each direction with a ratio of approximately 10:1 between the radial (X', Y') and axial (Z')

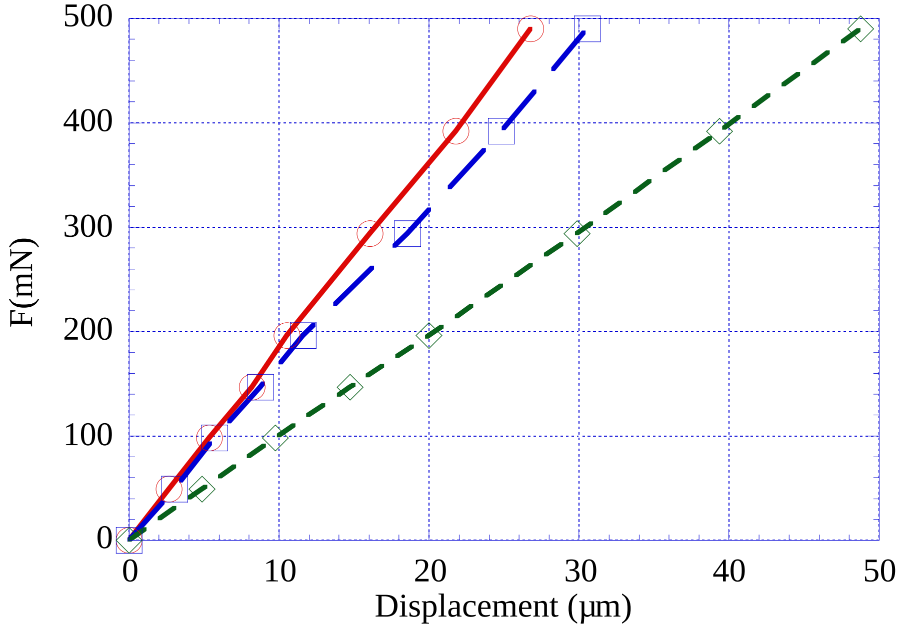

Figure 6 Force/Displacement curves with double diaphragms spaced 2.5 mm apart. `G`, `E`, and `A` represent the x', y' and z' direction, respectively. The stiffnesses in all directions lie within a factor of two of each other.

The use of Dual flexures as shown in Figure 4 allows a substantial increase in stiffness to be obtained in the radial direction, while only doubling the stiffness in the axial direction. The spacing of the flexures is then a independent parameter that can be adjusted to eliminate force lobing in all directions. The reduction in force lobing is illustrated in Figures 5 and 6.

Conclusions

E3D is ready for implementaion into 3-D measurement systems. The current version of the device is shown in Figure 7. A commercial incarnation of it is being developed for installation on an ultraprecision 3-D measurement system developed at Eastman Kodak Co.

Figure 7. The Three-Axis Measurement Probe mounted on an aluminum stand.