EXTENDED-RANGE XYZ LINEAR PIEZO-MECHANICAL SCANNER FOR SCANNING-PROBE AND SURFACE FORCE APPLICATIONS

FIELD OF THE INVENTION

The present invention relates generally to mechanisms to create precise scanning motions, and more particularly is a scanner that provides uncoupled motion in three orthogonal planes.

BACKGROUND OF THE INVENTION

Scanning Probe Microscope (SPM) instruments such as the Scanning Tunneling Microscope (STM), the Atomic Force Microscope (AFM), the Lateral Force Microscope (LFM) and the Friction Force Microscope (FFM), are research instruments that have been in use in universities and industrial R&D laboratories since the mid 1980's. These instruments allow for various imaging of surfaces as well as measurement of the intermolecular forces between two surfaces (or a small tip and a flat surface) in vapors or liquids. The distance resolution is typically on the order of 1 Å, which means that images can be obtained and forces measured at the atomic level. Over the years, SPM techniques have been improved and their scope extended so that it is now possible to image different types of surfaces and measure different surface properties and phenomena than historically possible.

SPM's operate by first bringing (positioning) the tip or 'sensor' surface near the "sample" surface, and then moving the tip vertically (normal mode) or laterally (scanning mode) to obtain a mechanical or topographical "image" of the sample surface or to measure some other property, such as the deflection force, that is sensed by the tip or sensor surface. The generation of an image or the measurement of a force is accomplished by monitoring the deflection of a cantilever spring supporting the tip as it scans the surface.

To obtain reliable images or property measurements, it is essential that the user be able to move the tip precisely in the z direction (up and down) as well as in the x and y directions (across the surface). Ideally, any induced motion in the, for example, x-direction does not produce unwanted motions in the y or z directions. In addition, given that relatively large areas usually need to be scanned, it is imperative that these motions be linear, e.g., precisely proportional to the applied voltage across the piezo element. Moreover, displacements in the normal "sensing" direction are typically in the angstrom range while those in the lateral 'scanning' directions are typically in the tens of microns range.

In most SPM and SFA applications the displacements of the 'tip', 'sensor surface' or 'sample surface' have different requirements in the lateral (x, y) and vertical (z) directions. Lateral motion is required for 'scanning', usually over large areas extending tens or hundreds of microns. In contrast, normal motion is generally required for topographical imaging or sensing some surface physical or chemical heterogeneity over distances in the nanometer range. These very different length scale requirements make it imperative to have a displacement transducer that separately optimizes and decouples the normal and lateral displacements.

However, the scanners used in existing SPM devices utilize a single piezoelectric tube to generate all of the available displacements, or they use multiple displacement generation elements that work against each other. Therefore, the normal and lateral motions generated are intimately coupled to each other in a way that makes it difficult to generate large lateral displacements and small normal displacements at the same time, while still maintaining the independence and linearity of the displacements.

The most common type of piezo element currently in use is the "sectored" piezo-electric tube in the style shown in FIGS. **1**A–C (top and side views). The piezoelectric tube is sectored into four quadrants, labelled 1–4. The 'sectoring' is achieved by removing the conducting metallic coatings from the outer and inner walls along the four strips 1–4, as shown. This process results in four electrically (but not mechanically) separate sections of the original tube.

Normal motion in the z-direction is produced by applying the same voltage differential, $\Delta V_1=\Delta V_2=\Delta V_3=\Delta V_4$, across the inner and outer conducting walls of the four sectored quadrants of the piezoelectric tube. A positive voltage differential ($\Delta V>0$) produces expansion ($\Delta z>0$) and a negative voltage differential ($\Delta V<0$) produces contraction ($\Delta z<0$) of the tube.

Lateral motions in the x and y directions are produced by applying different voltages across the four sectors of the tube. For example, if $\Delta V_1=-\Delta V_3$ and $\Delta V_2=\Delta V_4=0$, sector **1** will expand and sector **2** will contract. The net effect will be a bending of the end of the tube (which supports the tip) in the +x direction, as shown in FIG. **1**C. At the same time, one may apply additional voltages across the other sectors so as to produce simultaneous motions along different directions, for example, in the y or z direction. In this way, any desired motion along any desired direction in space can, in principle, be induced by applying suitable voltage differences across the four sectors of the scanner piezoelectric tube.

However, the simultaneous requirements of high sensitivity in the z direction and high range in x and y directions are not attainable with current art designs. There are two reasons for this: first, the motions are not perfectly independent but coupled. Thus, when motion is generated in the x direction, the movement of the tip more closely approximates an arc of a circle as opposed to a straight line. This effect is illustrated in FIG. **1**C. The resulting displacement in the x direction is therefore accompanied by a slight lifting of the tip in the z direction, as well as a slight rotation of the tip. These effects are negligible for small deflections, but become non-negligible when scanning over large lateral distances, which is often required.

Second, piezoelectric transducers become non-linear when high voltages are applied across them, i.e., the displacement is no longer proportional to the voltages applied across the different sectors. In addition, when operated in the non-linear region they tend to drift over time, i.e., their length changes with time because they are strained beyond their elastic limit. In most SPM applications, the piezo elements are subjected to voltages well above their linear range because of the need to have large scanning distances (typically>5 μm) which is often well above the linear region.

These two problems make it difficult to unambiguously interpret many images and other types of surface measurements quantitatively and sometimes even qualitatively. To alleviate these problems, which are related (large non-linear displacements also produce larger coupling between motions in the x, y and z directions), software packages are now available that can "correct" these defects. See e.g. U.S. Pat. No. 5,081,390, issued Jan. 14, 1992, to Ellings. The corrections are typically achieved by employing feedback sensors from the four sectors that allow the software to coordinate the voltages across them. Such software packages have limited success because piezoelectric elements are mechanically very complex. Their dimensions depend not