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IMPROVEMENTS IN MICROMANIPULATORS

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Summary

The Mark XIV G micromanipulator, capable of handling six microprobes, includes two units that possess six degrees of freedom. In addition to three degrees of translational freedom, there are pitch, yaw, and rotational degrees of freedom provided by a precision worm gear assembly. This micromanipulator aids in the testing and fabrication of microminiature electronic components including the assembly of piezoelectric bimorphs.

The piezoelectric-electromagnetic drive micropositioner utilizes piezoelectric bimorphs for generating y and z movements and an electromagnetic drive for producing the x movement. All three movements can be remotely controlled, utilizing conventional potentiometers for regulating the magnitude and direction of voltages required to produce the micromovements. Joystick controls can also be employed. The piezoelectric-electromagnetic drive micropositioner can be constructed to occupy a volume of less than 1 cm^3 exclusive of the microprobe holder.

"Functionally, the micromanipulator is a micropositioner with which one can place the tip of a microneedle, micropipette, or microelectrode in any position in a restricted space. At any instant, the tip of the microinstrument must be either where it is needed or out of the way. Over 200 different types of micromanipulators have been described since Schmidt (1859) published a description of his 'Microscopic Dissector'. Of these, perhaps 15 have reached the status of commercial production. These instruments range from simple rack and pinion assemblies to massive, accurately fitted ball-bearing slides actuated by precise feed screws or other driving mechanisms. Many commendable adaptations of this principle have been engineered in the excellent fine adjustments incorporated into the modern research microscope. Through the inclusion of spring-loaded, ball-bearing slides and various actuating mechanisms, the movements are smooth and without backlash."

"Although the precise positioning of microtools can be accomplished with feed screw type micromanipulators, there is a serious drawback in such instruments. They are inconvenient to operate, especially if a microtool is to be moved diagonally in three dimensions. Undoubtedly, this handicap led to the development of several varieties of lever or joystick actuated micromanipulators. With these instruments, the tip of a microtool can be positioned fairly rapidly which is an important advantage if the object is motile. Movements can be transmitted from the control lever to the slides by pneumatic or hydraulic means, in others, the movements are directly transmitted through mechanical couplings." (Kopac, 1964).

This Technical Report contains a brief description of two micromanipulators, especially constructed for this project. The first is the Mark XIV G with pitch, yaw, and roll movements in addition to three degrees of translational freedom. The purpose of this micromanipulator is primarily to aid in the fabrication and testing of microminiature electronic components, including the assembly of piezoelectric bimorphs. The second is a description of one of several micromanipulator movements that were designed and constructed utilizing piezoelectric components for driving two degrees of freedom plus an electromagnetic drive for the third degree of freedom.

Mark XIV G micromanipulator with six degrees of freedom.

The Mark XIV micromanipulator (Kopac, 1964), has the capability of handling six microprobes. All six stages have three degrees of translational freedom (x, y, and z axes) using 3-way Line ball bearing slides controlled by micrometer heads. Four of these units (Model J) are mounted on the left side of the microscope. They each have the range of 13 mm in all three axes. The larger Line micropositioners (Model H) are mounted on the right side of the microscope. These have a range of 25 mm with motion provided by micrometer screws with oversize thimbles.

Motion for pitch, yaw, and roll degrees of freedom are provided by a precision worm gear assembly. These are illustrated in Photographs 1 and 2, which show how these attachments are mounted on the Line model H micropositioners.

The bottom component provides the yaw movement. It consists of a phosphor bronze worm gear with 250 teeth. The steel worm has a diameter of 0.312 inch. The worm gear is attached to the bracket and the entire assembly moves as the worm is rotated. A special Barden double row ball bearing (Z96SS2x54) provides both stability and rotational freedom. The worm is held in place with an eccentric mount consisting of a pair of Barden ball bearings (R156SS3).

The pitch motion consists of a segment of a worm gear (initially with 250 teeth). The phosphor bronze worm gear is mounted between two Barden ball bearings (R156SS3), and the worm is eccentrically mounted using two Barden ball bearings (R156SS3). While the yaw assembly provides a range of 360°, the pitch assembly has a range of approximately 200°. Actually, only about 15° is needed for both since the approximate manual positioning of the microprobes can be used to compensate for a limited range.

The roll movement includes a phosphor bronze worm gear with 150 teeth and has an O. D. of approximately 0.967 inch. This gear is supported by a pair of Barden ball bearings (R156SS3). The worm is eccentrically mounted with a pair of Barden ball bearings (R156SS3). The eccentric mounts permit the most ideal relationship between the worm gear and worm. This arrangement also provides compensation for wear. The range of the roll movement is a full 360°. The microprobe holder is built into the center of the roll movement. Both pitch and roll movements are concentric.

As indicated in the photographs, the worm for each movement is rotated by turning a knob which extends from the worm. Each worm, as mentioned earlier, is constrained by the eccentric-ball bearing mounts.

All three control knobs can be extended to provide the most convenient operating positions.

Thus, Mark XIV G provides two micropositioners with six degrees of freedom with each under precise mechanical control. The positioning capability for translational degrees of freedom is less than 0.001 mm. The pitch and yaw movements have a 0.005 mm positioning capability, while the roll movement has a capability of less than 0.001 mm.

These special micropositioners are mounted on the right side of the Unitron Tool Makers microscope. This microscope has a mechanical stage with a positioning capability of less than 0.001 mm. The stage also supports a rack and pinion mount for rapidly raising or lowering the component to be assembled or tested.

The four Line model J micropositioners, mounted on the left side of the microscope, have a positioning capability of 0.005 mm. Two of these micropositioners are supplied with small right-angle slide-screw assemblies (Brinkmann HS), operating at a different angle, to give two additional translational freedoms and one roll movement which is not under mechanical control.

Piezoelectric-magnetic drive micropositioner.

The most successful adaptation which utilizes piezoelectric bimorphs for the y and z axes and an electromagnetic drive for the x axis is illustrated by photographs 3 and 4.

The problem of expanding the limited range of bender or twister bimorphs to drive microprobes in two axes of space (y and z) has been solved. Two degrees of rotational freedom with a large radius provide almost linear movements of the microprobes under the microscope. For this unit, a spring-loaded gimbal movement is used which works in opposition to the piezo-electric bimorphs. The problem was to expand the range of a bimorph from microns to tens or hundreds of microns.

Photographs 3 and 4 show the gimbal movement mounted on a 3-way micropositioner. The outer ringe of the gimbal movement has an O. D. of 0.760 inch. Freedom for rotating the rings of the gimbal movement are provided by miniature pivot ball bearings (RMB, series CF). These pivot bearings provide an excellent mechanical assembly yielding an instant and sensitive response to the delicate spring-loaded bimorph elements.

As seen in Photograph 3, the gimbal movement has 3 rings and two sets of pivots. Piezoelectric bender bimorphs are seen mounted in such a way that they can cause one of the two inner rings to be displaced when activated electrically. One causes movement in the z axis, while the other produces movement in the y axis.

Suspended below the gimbal movement is the electromagnetic drive. This consists of an electromagnet which works against a phosphor bronze diaphragm. Action of the electromagnet induces motion in the x axis, which is parallel to the axis of the microprobe holder. Its range is about 0.025 mm. This component can be seen most clearly in Photograph 4.

Activation and control of either piezoelectric or electromagnetic drives is easily accomplished by potentiometers which can be adjusted to provide the voltages and directional changes needed. There is a separate potentiometer for each degree of freedom. For most control requirements, a conventional 270° potentiometer is satisfactory. For finer controls, a 3-turn potentiometer can be used. The piezoelectric components operate on voltages up to 180 volts which are supplied by small "B" type batteries. Separate batteries are used for each degree of freedom. The electromagnetic drive requires voltages up to 22.5 volts.

Control of movements in both piezoelectric and electromagnetic drives thus is basically no different than the control of a movement activated by turning a micrometer screw (Kopac and Harris, 1962; Kopac, 1964). For simplifying the controls, a double potentiometer with concentric knobs can provide movements in two axes and a third potentiometer provides movement in the third axis. Obviously, both piezoelectric and electromagnetic controls can be remote. If joystick controls are needed, these can be provided by Precision Miniature Joysticks (Bowmar AM-3244) for two movements, with a separate control (potentiometer) for the third movement.

The remote control of micropositioners is possible by pneumatic controls such as in the de Fonbrune or Cailloux micromanipulators (Chambers and Kopac, 1961; Kopac, 1963). It is also possible in the electric micromanipulator, formerly made by American Optical Company (Kopac, 1964). The piezoelectric micromanipulator, by Ellis (Ellis, 1953), is capable of remote controlling.

The piezoelectric-electromagnetic micromanipulator described in this report is the most compact of the remotely controlled micromanipulators now available. Indeed, the prototype described here is a "monster" compared with the size that can be made utilizing piezoelectric or electromagnetic drives. If necessary, a micromanipulator can now be constructed in which the entire positioner assembly can be limited to a volume of less than 1 cm^3, exclusive of the microprobe holder.

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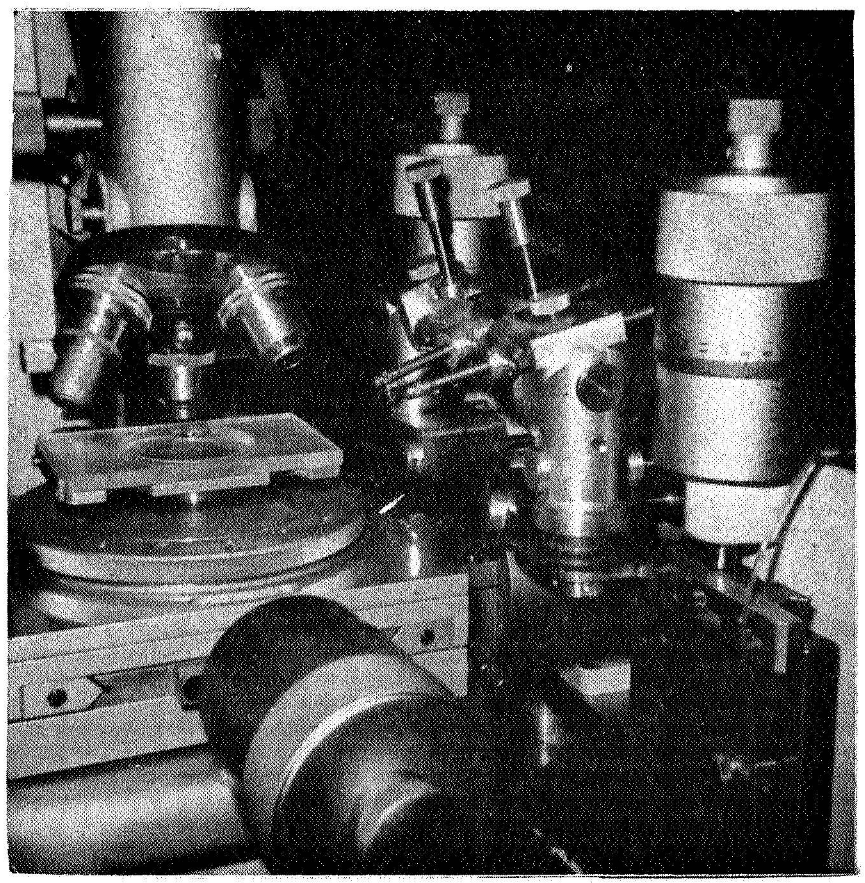
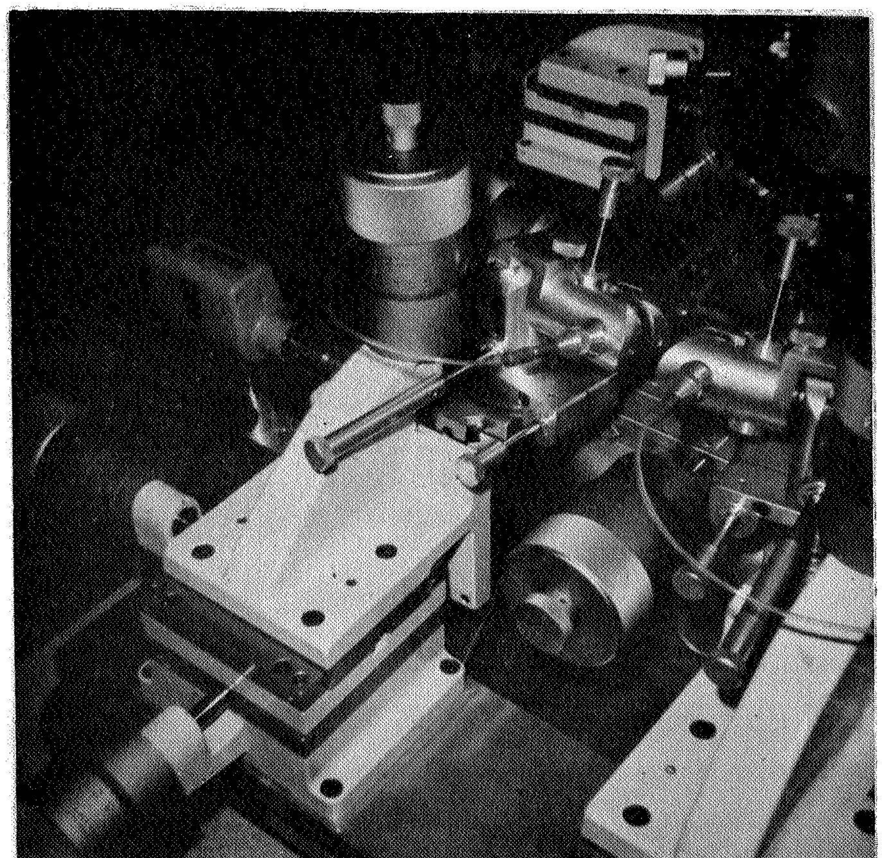
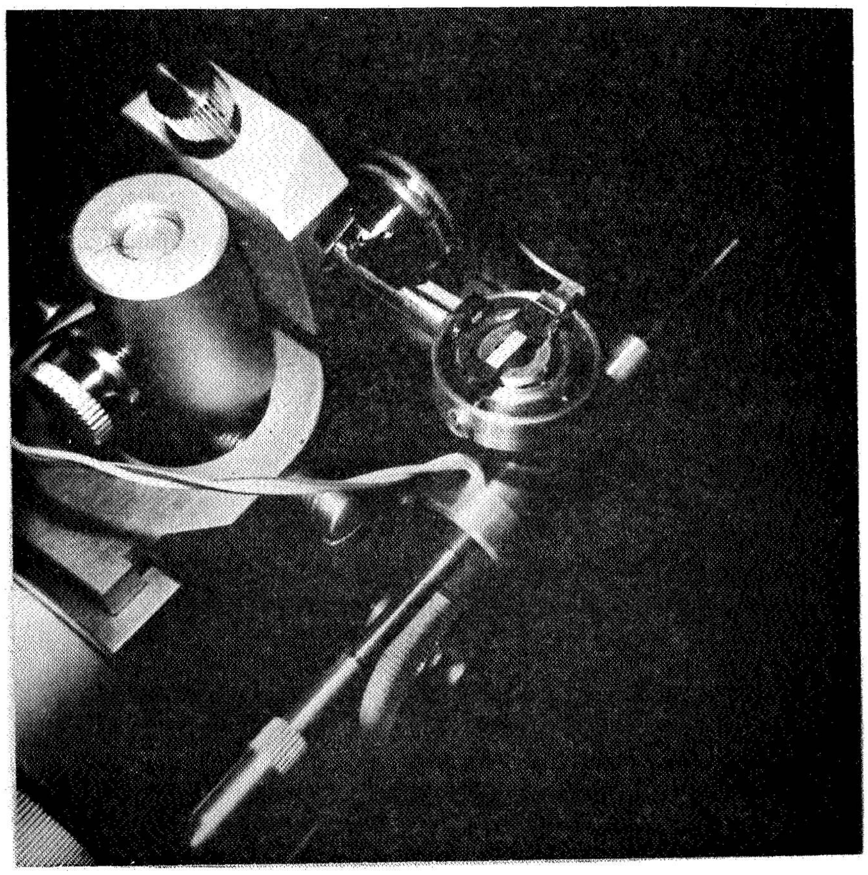
Photograph 1. Pitch, yaw, and roll movements mounted on Line model H positioners. Two large micrometer heads are shown which supply movement in the z axis. The large micrometer head in the foreground is used for moving the mechanical stage in the y axis.



Photograph 2. Another view of the pitch, yaw, and roll movements which also shows the control knobs for turning the worms in the worm gear assemblies. All three micrometer screws for the Line model H positioner may be seen. In the background is one of four Line model J positioners. The second micrometer head for moving the mechanical stage in the x axis is seen between the two model H positioners.



Photograph 3. The piezoelectric-electromagnetic drive is shown. It is supported by a clamp mounted on a 3-way positioner. The gimbal movement with its three rings and two sets of pivots is clearly shown as are the two piezoelectric bimorphs mounted on top of the rings. Supported by the inner ring of the gimbal movement is the electromagnetic drive which carries the microprobe holder.



Photograph 4. The piezoelectric-electromagnetic assembly is shown mounted on the z movement of a 3-way positioner. The electromagnetic drive is shown suspended below the gimbal movement. The piezoelectric bimorphs can be seen mounted on top of the gimbal movement. They are mounted at right angles to one another.