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Micro gripper for micromanipulation using IPMCs (ionic polymer metal composites)

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Electro active polymers (EAPs) exhibit large electrically induced strains (bending or stretching) with electrical stimuli. EAPs are utilized as actuators in micro gripper and micromanipulator in micro robotics activities. Remote center compliance (RCC) based micro gripper is developed to facilitate insertion of peg-in-hole (PIH) for micro assembly operations. An effect of RCC compliance during PIH operation is analyzed using ionic polymer strips. Experimental performance of insertion of peg during assembly, as compared with bending moment model of IPMC based micro gripper, shows misalignment of peg in handling operation.

Keywords: EAP, IPMC, Micro assembly, Micro gripper, Peg-in-hole (PIN), Remote-center-compliance (RCC)

Introduction

Micro system technology has a critical task for handling and integration of miniature components in micro assembly[1-3]. Remote center compliance (RCC) device that controls micro assembly operation[4-9] consist of micro gripper with manipulation arm. Micro gripper consists of three fingers linking to the wrist. Complete assembly of micro gripper is connected to a single link using ionic strip. Single IPMC is utilized as flexible micro robotic arm in micromanipulation. Single link lifts peg during peg insertion. Small misalignment occurs due to translational or rotational movement between centerlines of peg and hole. Alignment is controlled by force of IPMC, generated by electrical pulses.

Electro active polymers (EAPs) have large actuation strain, quiet operation and damage tolerance, as compared to shape memory alloy (SMA), silicon and piezoelectric materials[10,11]. EAPs broadly are divided into two distinct groups[12-15]: i) electronic (driven by electric field or coulomb forces); and ii) ionic (involves mobility or diffusion of ions). Unlike piezoelectric and shape memory alloy (SMA), IPMC that requires < 5V to activate can be used in micro remote arm manipulator (RAM) and compliance robots[16,17].

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This paper presents a three finger micro gripper with micro robotic arm of IPMCs.

Ionic Polymer Metal Composites (IPMC): Chemical Properties and Behavior

Ionic strips are manufactured using ion fluorinated polymers such as Nafion®, Flemion®, Teflon® and their modifications[18,19]. Thin Nafion polymer sheet is layered with highly conductive metal like platinum or gold, making combined membrane, named ionic polymer metal composite (IPMC) (Fig. 1). The membrane (ionic sulfonate groups) is permeable to water and cations[20]. This insures that IPMC sample is fully hydrated during actuation. Under alkali environment, actuation of IPMC is fast due to presence of sulfonate groups, which reacts with Nafion film cations. These actuations of IPMC

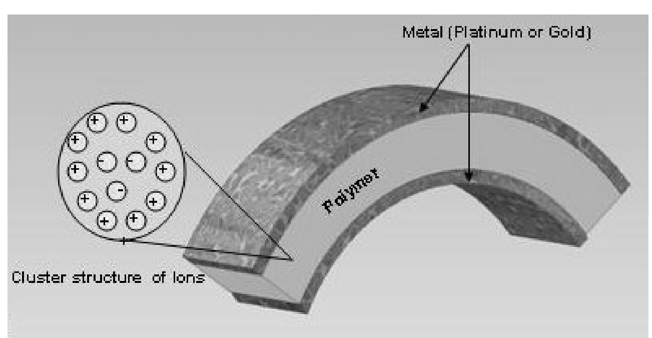

Fig. 1—Schematic representation of IPMC material

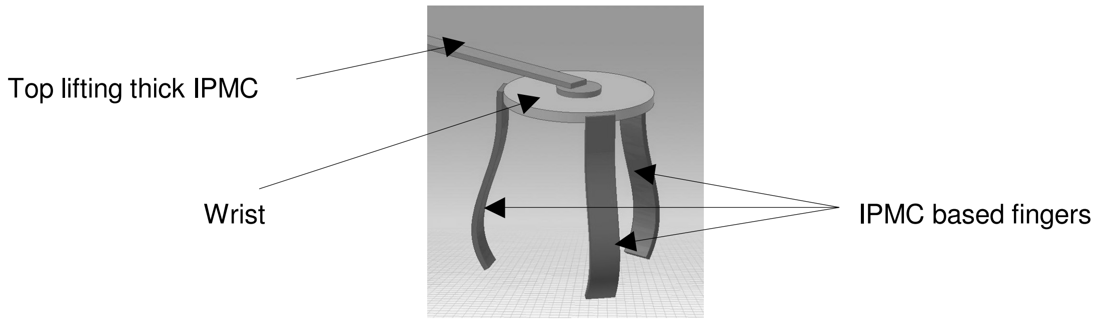

Fig. 2—CAD model of RCC based micro gripper using IPMC

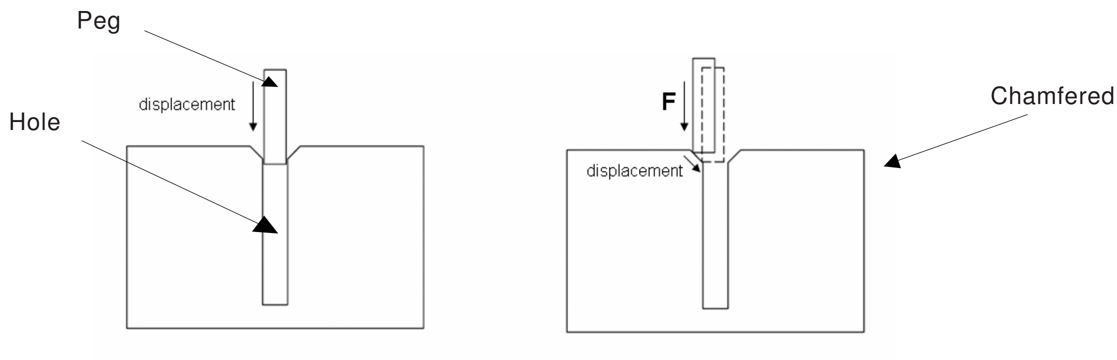

Fig. 3—Lateral and angular misalignment

material under dry/moist environment are used in the development of micro gripper.

Design of RCC based Micro Grippers

Major advantage of IPMC micro gripper over a rigid gripper is that it can function as a remote centre compliance (RCC) device. In RCC device, basic requirement of an assembly is to achieve desired position by controlling action. IPMC micro gripper has three fingers (thin ionic strips, 40 mm x 10 mm x 0.2 mm) for holding the object and a single link (thick ionic strip, 40 mm x 10 mm x 2 mm) for micromanipulation of object (Fig. 2). There are two conditions considered for introducing peg-in-hole (PIH) operation in the system: I) Axis of peg coincides with axis of hole (lateral alignment); and ii) Axis of peg does not coincide with hole axis but both axis will be parallel to each other (Fig. 3).

Mechanical Characteristics of IPMC and Micro Gripper

Micro gripper design depends upon geometry and payload capability. Voltage and bending moment relationship is obtained using theory of beam. Insertion depth of peg is derived when micro gripper is in operation.

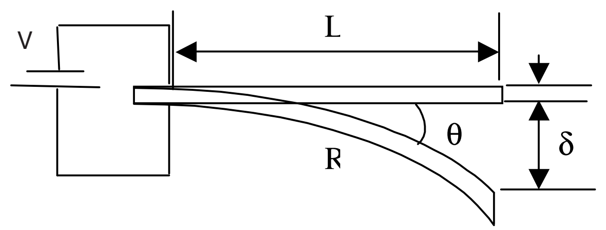

Fig. 4—Ionic strip in cantilever configuration

Bending Moment Model for IPMC Analysis

Consider a cantilever beam with a moment applied at the free end and allowed for end deflection of beam of length (Fig. 4). Curvature of cantilever beam can be calculated as

$$\kappa = \frac{1}{R} \cong \frac{2\delta}{L^2 + \delta^2} \quad \ldots(1)$$

Curvature of IPMCs is experimentally measured and voltage vs curvature relationship shows almost linear behavior as

$$\kappa = K \times V \quad \ldots(2)$$

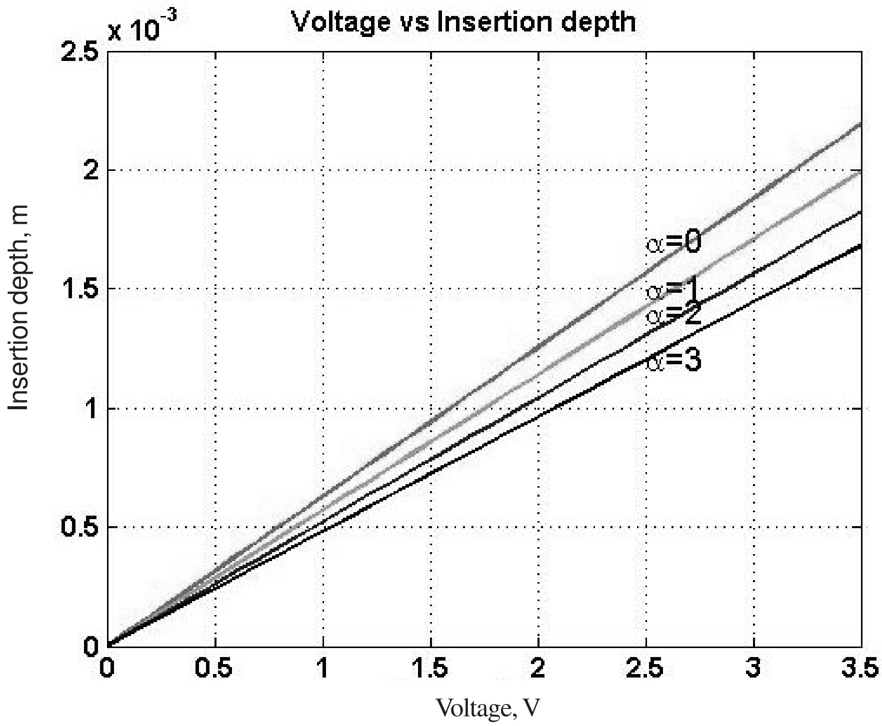

Fig. 5—Performance of insertion depth of micro robotic arm and voltage

Relationship between bending moment and applied voltage is expressed as

$$M = \frac{1}{12}.K.E.w\ .t^3.V \quad \ldots(3)$$

Force and Moment analysis of RCC based Micro Gripper

Frictional forces are calculated when IPMC based fingers hold the object along with peg (micro pin). Resultant forces and moment are obtained as

$$N = \frac{(F_1 + F_2 + F_3) + W}{Cos\theta} \quad \ldots(4)$$

Total moment is

$$M = d/2 * [F_1 - (F_2 + F_3)Cos\phi] \quad \ldots(5)$$

In angular alignment case, normal reaction is

$$N = \frac{(F_1 + F_2 + F_3) + W}{Cos\ \theta Cos\ \alpha} \quad \ldots(6)$$

Total moment is

$$M = d/2 * [F_1 - (F_2 + F_3)\ Cos\phi]\ Cos\alpha \quad \ldots(7)$$

Reaction force and moment depends on alignment/ orientation angle (α).

Theoretical Analysis of IPMC based Micro Robotic Arm for Micro Gripper

Forces in micro robotic arm, while in operation, are analyzed. Total moment is

$$M_n = NSin\ \theta X_n \quad \ldots(8)$$

Substituting value of N from Eq. (8)

$$M_n = \frac{[(F_1 + F_2 + F_3) + W\ ]Sin\ \theta}{Cos\ \theta Cos\ \alpha} X_n \quad \ldots(9)$$

If $F_1+F_2+F_3+W= \xi$ =constant and general equation is,

$$[M_n] = \xi \frac{\tan\theta}{Cos\alpha}[X_n] \quad \ldots(10)$$

By equating Eq. (11) and Eq. (3), insertion depth is obtained as

$$[X_n] = (\frac{1}{12}\text{K.E.}w.t^3)\frac{\cos\alpha}{\xi\tan\theta}[V_n] \quad \ldots(11)$$

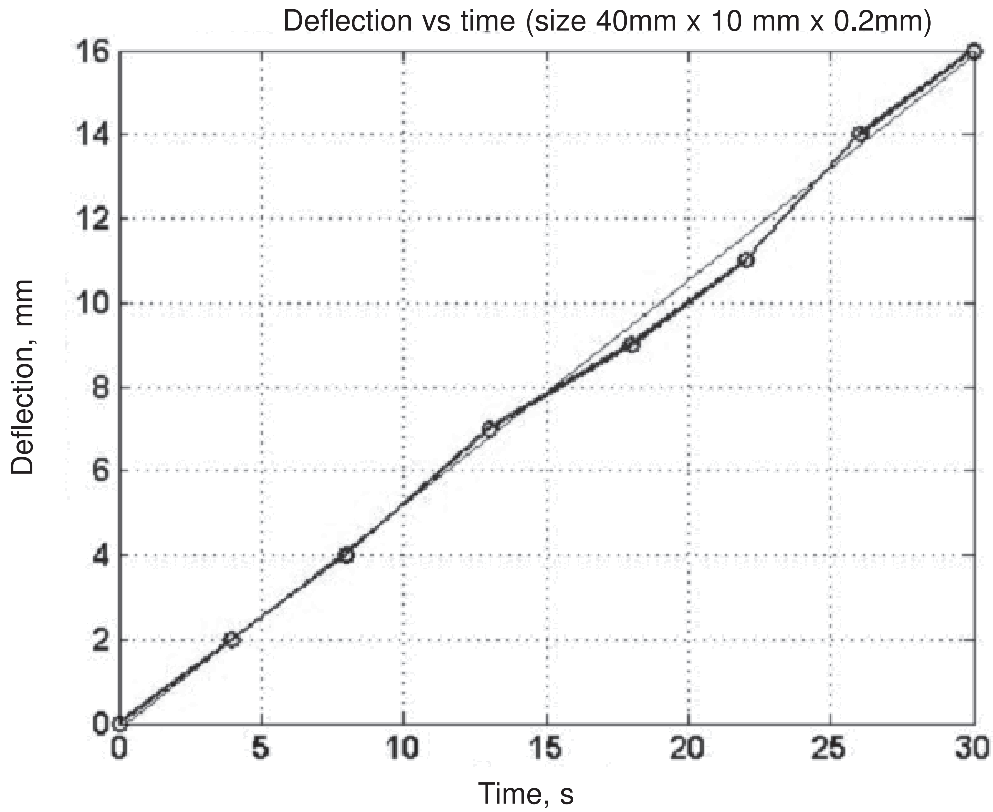

Fig. 6—Deflection responses with applied DC voltage

where, L, length of beam; R, radius of curvature; δ, deflection of beam; κ, curvature of beam; K, path constant; V, voltage given to IPMC; M, bending moment; E, modulus of elasticity; W and t, width and thickness of IPMCs; F1,F2 and F3, force generated by IPMC; W, weight of peg; N, normal reaction; ϕ, resolving component of normal reaction; α, alignment angle; V_n, general term of voltage; M_n, general term of bending moment; Xn, general term of top IPMC; X+Xdi, different position of top IPMC; ξ, constant.

Insertion depths of micro robotic arm at α=0, 1, 2, 3…..n are calculated. To analyze divergence effect of micro robotic arm, design parameters are: actual displacement, up to 10 mm; Young modulus, 140 MPa; response time, 1-20 sec; max. bending curvature, 0.020-0.030/mmV; applied voltage, 1-4 V; and size, 40 mm x 1 0 mm x 2 mm. Insertion depth (X_{di}) vs voltage shows (Fig. 5) that divergence effect of IPMC based micro robotic arm always decrease with α. Maximum insertion depth of peg is up to 0.0022 mm.

Experimental Setup

Micro gripper consists of three IPMC fingers (40 mm x 10 mm x 0.2 mm each) and can actuate in dry/wet environment. These ionic strips are custom made weighing around each 0.2 g. All three strips are attached to wrist of micro gripper (perspex sheet). Platinum sides of strip are connected to a signal amplifier driven with PCI computer software by electrical means. In computer, a digital analog output card (DAC) is already inserted. Trans-amplifier with power supply is used to amplify signal output. Computer code generates various waveforms (sinusoidal, square, triangular) and saw tooth signals at desired frequencies and amplitudes when voltage is applied up to 10 V. One end of top thick ionic strip size is integrated with RCC device and other end is held in holding device. For top thick ionic strip, input voltage range is separately given by custom-made power supply, which is able to perform lifting operation. Dial gauge placed measures peg insertion depth, which allows for misalignment during operation. For alignment/ orientation angle measurement, suitable slip gauges are placed during experimentation.

Results and Discussion

Angle α is varied (0-3°). Each ionic strip, tested separately in cantilever configuration by applying

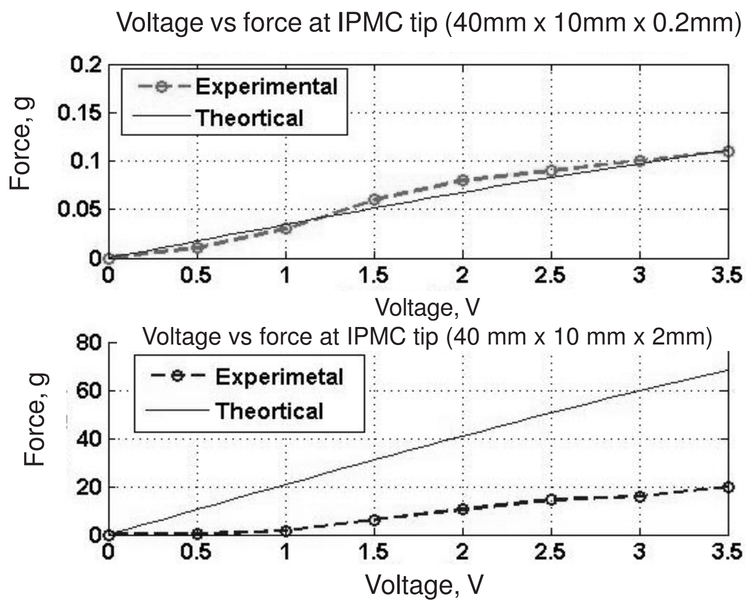

Fig. 7—Tip force responses of IPMC with applied DC voltage

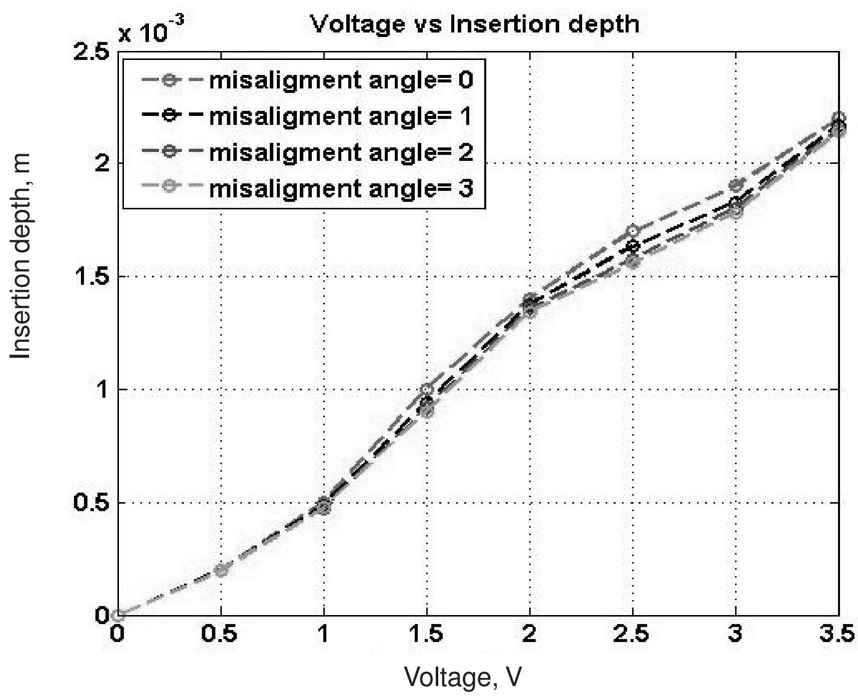

Fig. 8—Experimental performance of peg insertion depth

voltage (0-4 V) through computer, bend in positive side every time and reverse effect is seen after changing polarity. Deflection of free end is measured up to 3.5 V (Fig. 6). Deflection of ionic strips decreases due to moisture evaporation[21].

Load cell placed near to ionic strip with cantilever mode facilitates payload capabilities. Voltage measured in both sides of strip is compared with theoretical tip force of ionic strip through pseudo rigid body model[22] (Fig. 7), which shows force-voltage relationship with flexible segment of IPMC. Maximum tip forces were found similar to pseudo rigid body model with large deformation of thin ionic strips. In case of thick ionic strip, experimental value shows slightly low performance as compared to theoretical values due to migration of hydrated cations (H+, Li+ ion) in the strip. Experimental performance of insertion depth corresponds to voltage (Fig. 8). Peg is found slightly mismatched with respect to hole while angular alignment occurs in operation. Insertion depth agrees with theoretical behavior when α increases from lateral position ($\alpha=0^0$). From experimental data, insertion depth of peg has slight divergence from lateral position due to mishandling of peg. Apart from lateral position ($\alpha=0^0$), axis of peg is not coincided with axis of hole due to variation of alignment angle. However, axis of peg is parallel to axis of hole while peg touches at chamfered portion.

Conclusions

A RCC based micro gripper using IPMC has been developed. A single IPMC strip is used as flexible low force robotic arm that allows lifting micro object with small alignment in either position or orientation independently. Insertion depth decreases with alignment angle (α) and increases with applied voltage. For small orientation, peg can touch easily at hole and effect of insertion depth is negligible as axis of peg coincides with axis of hole.

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