 ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

Design and Analysis of Piezoelectric Based a Novel Bottleneck Shape Micro Gripper

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Abstract
A Micro Electro Mechanical System (MEMS) based piezoelectric actuator is a micromechanical device that produces parallel movement of gripping arms by piezoelectric material. Piezoelectric actuated microgripper used to grip and handle the miniature parts where study of displacement with voltage are important.In this paper two typical design of microgripper w.r.t. different actuator heights and widths are presented and analyzed. After analyzing, the previous two designs (which gives less jaw movement and higher voltage) we present a novel microgripper mechanism based on specific design requirements for micromanipulation. This microgripper is designed in COMSOL designing tool for the piezoelectric materials such as lead zicronate titanate (PZT), have been designed to achieve displacement at low voltage. The performance of the microgripper and the results show that the microgripper can grasp micro objects with the maximum jaw motion of 1.3008μm corresponding to the 2400-V applied voltage.

Keywords
Microgripper, Piezoelectric Actuator, Piezoelectric material PZT.

I. Introduction
Micro Electric Mechanical System (MEMS) or Microsystems is developingequipment, it has a big credible to reshape life patterns for upcoming microelectronics technology. This technology is used in many applications including biomedical, telecommunication, and consumer electronics and also in defense application [9].An actuator has been responded by moving, positioning, regulating, pumping, filtering and controlling the environment for some desired results [8].More specifically, an actuator is a device that converts electrical energy into motion or mechanical energy. In this paper, we are focusing on design and analysis of piezo actuator for micro gripper towards handling of the micro parts. There are generally two behaviors of gripping for the jaws: angular and parallel [12]. Angular lead to a sliding motion between the gripped object and themicrogripper jaw, while parallel gripping provide a smooth distribution of the gripping force over the manipulated sample and minimize the stress distribution on the grasped objects [9].Many different kinds of microactuators have emerged in recent years [4,7,11-10]. Each kind of actuators possesses its own unique benefits, such as providing large force, compact size, low cost [8], consuming less power, offering long displacement and holding high actuating speed [3]. However, none of them could carry all advantages, in fact, some trade-offs exist between these advantages.The major contributions of this paper isthe effect of varying heights and widthsof actuator has been studied and analyzed the displacements of microgripper jaw has been proposed at low voltage.The remainder of the paper is organized as follows. Section II consists of a design detail of Microgripper. Section III defines the designing of Microgripper depending upon various parameters like displacement, voltage. Section IV present a new shape piezoelectric Microgripper. Section V describes the comparative study of microgripper with various actuators. Section VI concludes the paper.

II. Design Detail of Micro Gripper
The actuator is made of piezoelectric materials because the piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials. The piezoelectric effect is a reversible process,exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force), and the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field) [2]. In this paper we usepiezoelectric material i.e. Lead zirconate titanate (PZT) crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. Piezoelectric actuator [5] that controls in the longitudinal mode is used in this design. Longitudinal direction creates a lifting movement in the construction. Simultaneously, tightening in transversal direction closes the gripper and allows it to move objects. The middle arm embodies the piezoelectric actuator that made of lead zirconate titanate (PZT) which is piezoelectric material.Fig. 1 shows the flow chart of designing of microgripper. The Model Wizardcontains a series of pages, to help in design a model, the Geometry toolbar is a part of the main toolbar and has to perform geometric operations. After adding a Model, to add definitions with a local scope like view, contact pair etc. called global definitionsand thenapplying the material. Meshing is necessary is a partition of the geometry into small units of a simple shape. After that results analysis and study there are these main operations features: plots, derived values and tablesand exports.
The model of Piezoelectric Actuated Microgripperisshown in fig. 2. It consists of parallel mechanism with flexure hinges which are arranged parallel to each other and mounted on the base and contact point.The piezoactuator serves as a movement to the gripping arms and graspof the object can be achieved when the voltage is applied to the piezoactuator.

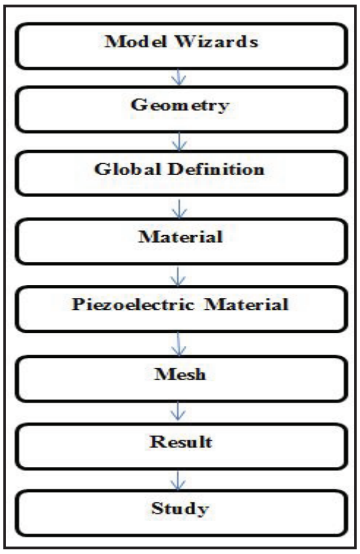

Fig. 1: Flow Chart for Designing the Microgripper

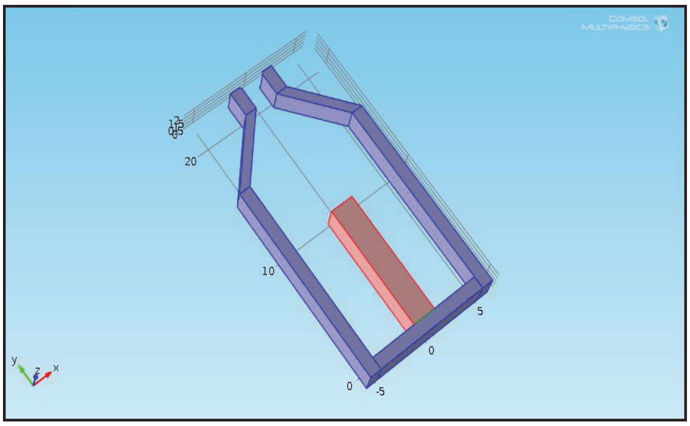

Fig. 2: Model of a Piezoelectric Actuated Microgripper

It has been observed from Fig. 2, the red color shows actuator is made of lead zirconate titanate (PZT) which is piezoelectric material and blue color shows the gripper itself consists of polycrystalline silicon (poly-Si). Both materials are available in COMSOL MULTIPHYSICS material libraries.

III. Related Work of Designing of Microgripper

A. Microgripper With Varying The Actuator Heights

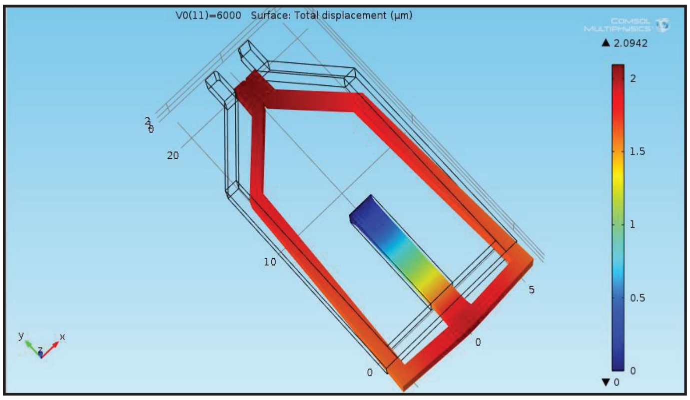

Fig. 3: Simulation of Microgripper Device with 8µm Actuator Height

The simulation of piezoelectric microgripper device as shown in Fig. 3 has displacement to voltage relationship, which is function of the change in actuator height with 8µm, 10µm and 12µm. The device shows displacements of 2.0942µm,2.2017µm and 2.205µm at6000 V with above mentioned heightsrespectively. The top ends shows the gripping pads, the black lines shows the initial position of the microgripper and the colored lines shows the final position of the gripping pads.

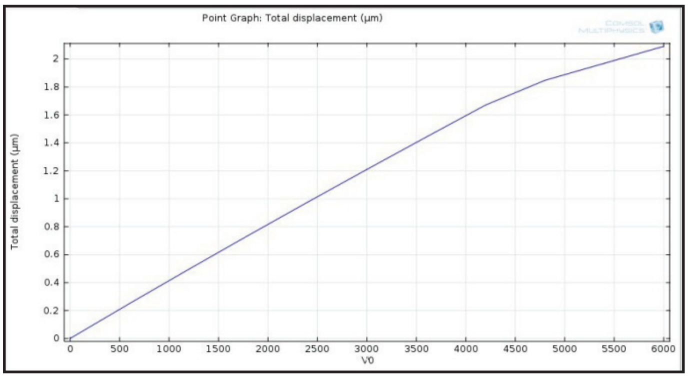

Fig. 4: Displacement Vs. Voltage Curve of 8µm Actuator Height

The fig. 4 displacements results corresponding to the 8µm height are present. The displacements for 8µm actuator height which linearly increases between 0-4800 V and it slightly decreases between 4800 - 6000 V, there are change in the displacements w.r.t. actuation voltage. The displacement achieved by microgripper is 2.0942µm at 6000 V.

The displacements corresponding to the 10µm actuator height shown in fig. 5 linearly increases between 0-5500 V and it slowly decrease between 5500 -6000V, there is change in the displacement w.r.t. actuation voltage. The displacement achieved by microgripper is 2.2017µm at 6000 V.

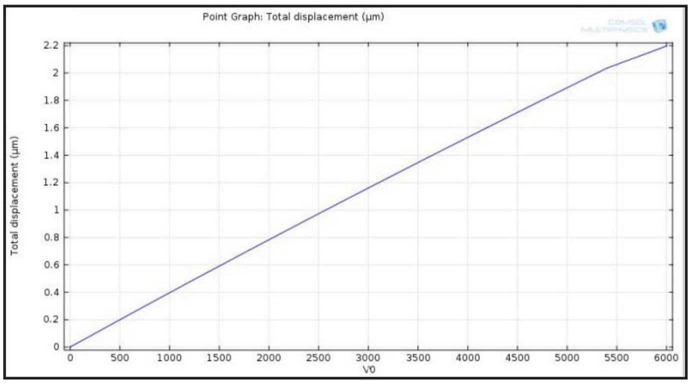

Fig. 5: Displacement Vs. Voltage Curve of 10µm

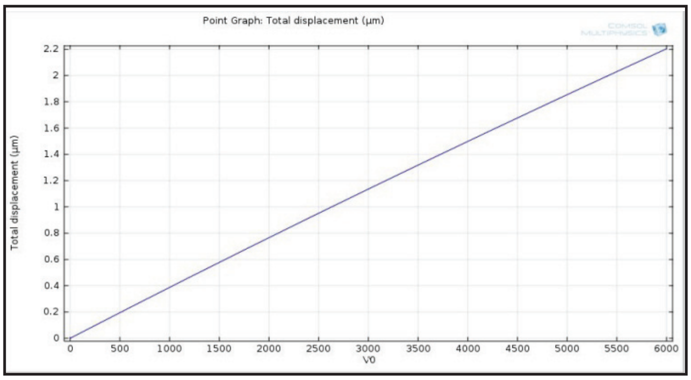

Fig. 6: Displacement Vs. Voltage Curve of 12µm

The fig. 6 showsthat the displacements corresponding to the 12µm actuator height which linearly increase from 0-6000 V, there is no change in the displacements w.r.t. actuation voltage. The displacement achieved by microgripper is 2.205µm at 6000 V.

B. Microgripper With Varying The Actuator Widths

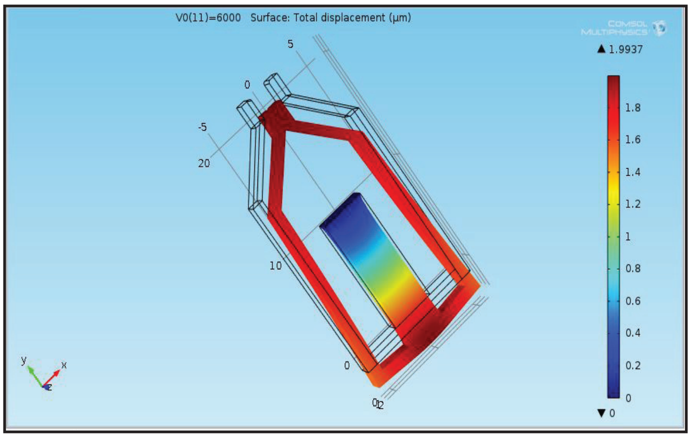

Fig. 8: Simulation of Microgripper Device with 4µm Actuator Width

The simulation of piezoelectric microgripper device as shown in Fig. 8 has displacement to voltage relationship, which is function of the varying in actuator widths with 1µm, 2µm and 4µm. The device shows displacement of1 µm, 2µm and 4 µm actuator widths are 2.0059µm, 2.2017µm and 1.9937µm respectively at 6000 V.

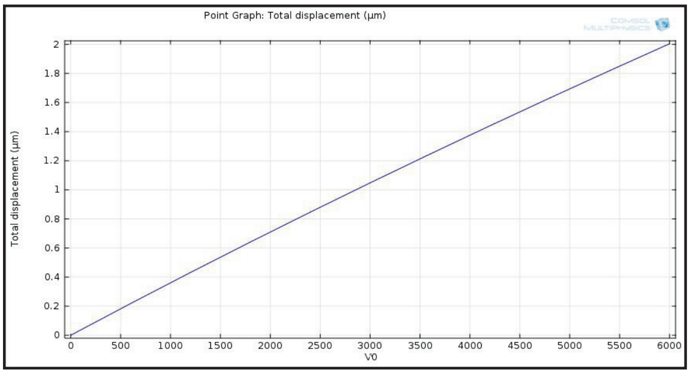

Fig. 9: Displacement Vs. Voltage Curve of 1µm

The fig. 9 shows the displacementscorresponding to the 1µm actuatorwidth which linearly increase from 0-6000 V, there is no change in the displacements w.r.t. actuation voltage. The displacement achieved by microgripper is 2.0059µm at 6000 V.

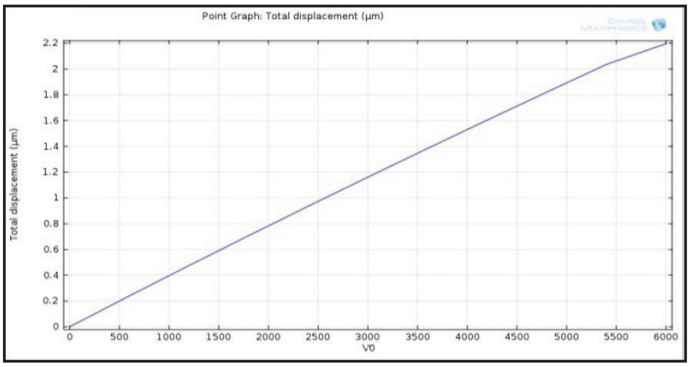

Fig. 10: Displacement Vs. Voltage Curve of 2µm

The displacements are shown in Fig. 10 corresponding to the 2µm actuator width which is linearly increases between 0-5400 V and it slowly decrease between 5400 - 6000 V, there is change in the displacement w.r.t. actuation voltage. The displacement achieved by microgripper is 2.2017µm at 6000 V.

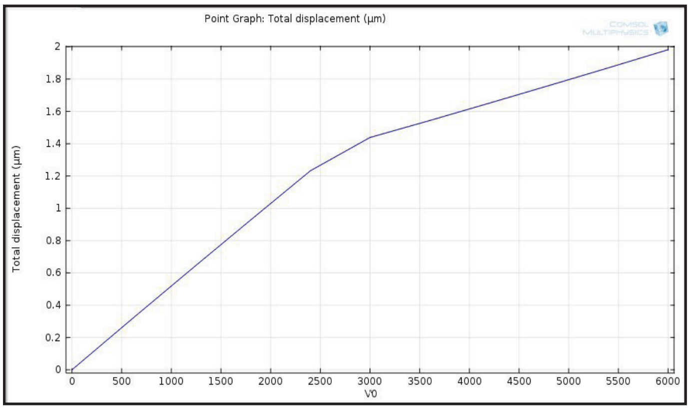

Fig. 11: Displacement Vs. Voltage Curve of 4µm

The Fig. 11 shows the displacementscorresponding to the 4µm actuatorwidth which linearly increase between 0-2400 V and it slightly decreases between 2400-3000 V, further rapidly decrease from 3000 V to 6000 V, there is change in the displacements w.r.t. actuation voltage. The displacement achieved by microgripper is 1.9937µm at 6000 V.

IV. A Novel Design of Bottleneck Shape Piezoelectric Microgripper

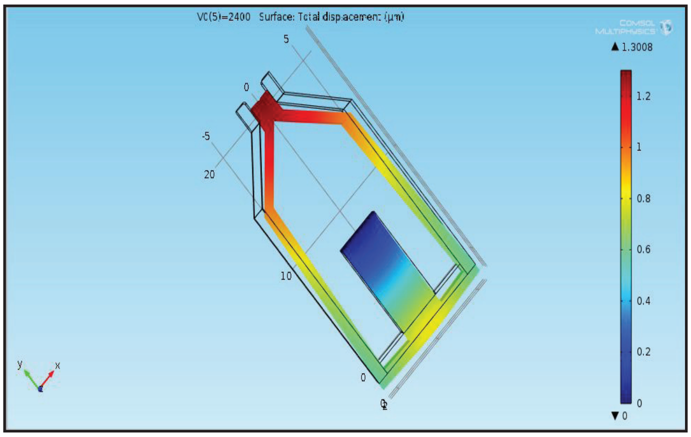

Fig. 13: Simulation of Bottleneck Shape Microgripper

As we design above different microgripper using various parameters like displacement, height, width, voltage etc. As we conclude that by using varying the various heights and widths of actuator then founda new shape microgripper which is called as bottleneck shape microgripper.The simulation of bottleneck shape piezoelectric microgripper device as shown in Fig.13 has displacement to voltage relationship, which is function of actuator height with 8µm and actuator width with 4µm. The device shows maximum displacement of 1.3008µm at 2400 V. The top ends shows the gripping pads, the black lines shows the initial position of the microgripper and the colored lines shows the final position of the gripping pads.

V. Comparative Study of Micro Gripper Using Various Piezoelectric Actuators

Fig. 7 shows that the performance of microgripper in terms of displacements w.r.t. actuation voltage for various actuator heights. The blue line shows the displacements of actuator with height 8µm, red line for height 10µm and green line for height 12µm. From Fig. 7, we clearly observed that up to 4800V the displacement increased with voltage. After 4800 V, the 8µm height actuator, displacement decreases.So we can conclude from Fig. 7 thatat lower voltages (0-4800 V) the actuator with minimum height gives the better results, but as we increase the voltage after 4200 V, so 8µm actuator it better than otheractuators (10µm and 12µm actuator heights).

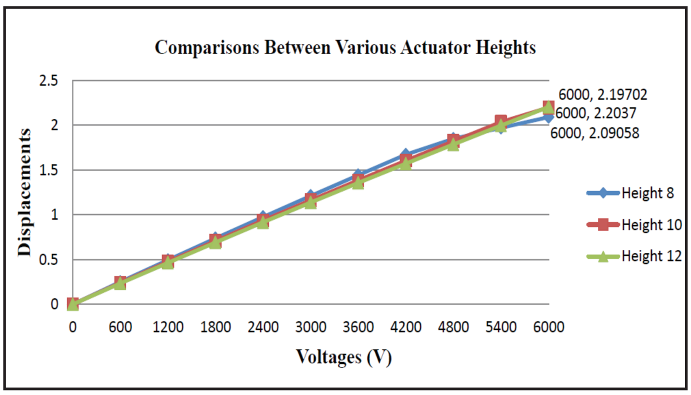

Fig. 7: Comparisons between various Actuator Heights

Table 1: Comparisons Between Various Heights

Voltages (V)	Displacements(μm)		
	Height 8μm	Height 10μm	Height 12μm
0	0	0	0
600	0.24986	0.23938	0.23353
1200	0.49543	0.47494	0.4637
1800	0.73707	0.70694	0.69069
2400	0.97512	0.93561	0.91468
3000	1.20988	1.16115	1.13583
3600	1.44161	1.38376	1.35428
4200	1.67057	1.60362	1.57017
4800	1.84739	1.82088	1.78362
5400	1.96919	2.0357	1.99476
6000	2.09058	2.19702	2.2037

Table 1 shows that the different displacements at various heights of actuators.

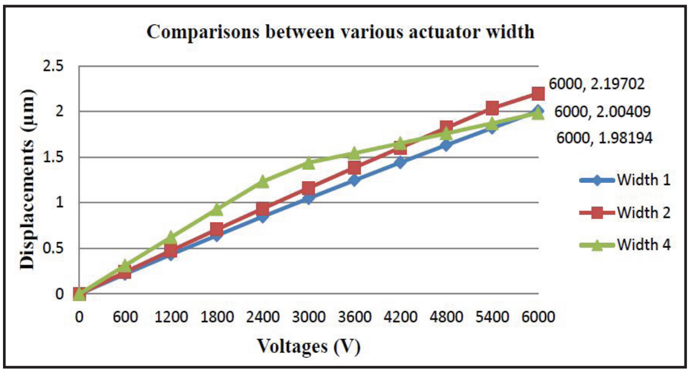

Fig. 12: Comparisons between various Actuator Widths

The Fig. 12 shows that the comparison of displacements w.r.t. actuation voltage of various width of actuator. The blue line shows the displacements of actuator with 1μm width which shows very poor displacement as compare to other two actuators. The red line for width 2μm actuator which shows better result than the 1um width actuator till 4200 V and it surpass the other actuator i.e. 4μm. The green line for width 4μm actuator is extremely better than the other two till 3000 V, after that the difference is slightly less than other two but still better till 4200 V.

Table 2: Comparisons between Various Widths

Voltages (V)	Displacements(μm)		
	Width 1μm	Width 2μm	Width 4μm
0	0	0	0
600	0.21818	0.23938	0.31239
1200	0.43180	0.47494	0.62168
1800	0.64112	0.70694	0.92822
2400	0.84638	0.93561	1.23228
3000	1.04782	1.16115	1.43848
3600	1.24564	1.38376	1.5432
4200	1.44001	1.60362	1.65088
4800	1.63111	1.82088	1.75977
5400	1.81909	2.0357	1.86983
6000	2.00409	2.19702	1.98194

Table 2 shows that the comparison of displacements w.r.t. actuation voltage of various width of actuator.

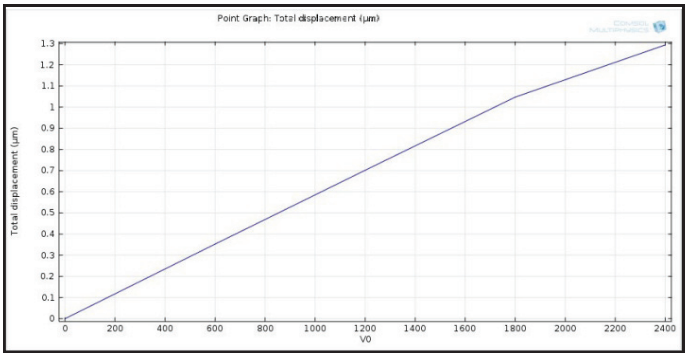

Fig. 14: Displacement Vs. Voltage Curve

The displacements Vs. voltage curve of bottleneck shape microgripper shown in fig. 14. The displacements are increases between 0–1800 V and then decreases from 1800 V to 2400 V, there is change in the displacements w.r.t. actuation voltage. The displacement achieved by microgripper is 1.3008μm at 2400 V.

Table 3: Results of Bottleneck Microgripper

Voltages (V)	Displacements (μm)
0	0
600	0.3543
1200	0.7049
1800	1.0523
2400	1.3008

In Table 3shows,the displacements w.r.t. actuation voltage of bottleneck shaped microgripper. The maximum displacement achieved by microgripper is 1.3008μm at 2400 V.

VI. Conclusion

Here we concluded that when actuatorby varying actuator heights as 8μm, 10μm and 12 μm at 6000 V then the device shows displacements as2.0942 μm,2.2017 μm and 2.205μm respectively, and, from this it can be concluded that 8μm is better thanamong these two. The variations of actuator width are also considered in the microgripper. Theanalysis of varying the actuator widthswith 1μm, 2μm and 4μm at 6000 V, then thedevice shows displacementsare 2.0059 μm,2.2017 μm and 1.9937 μm respectivelyand it conclude that 4μm actuator width is betterthan among these above two, and as it take maximum displacement at lower voltage others.Finally, we concluded that when we decrease the actuator height and increase the actuator width corresponding to the actuator voltage, then found the maximum displacement is 1.3008 μm at lower voltage i.e. 2400V. So by the analysis of above all results, we develope a new design of microgripper called bottleneck shape microgripper which gives efficient performance i.e. higher displacement at lower voltage.

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