Sizing Optimization of Microactuaor In-plane Based on Ansys Workbench

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Abstract. One new type piezoeletric microactuator was designed in this paper, in order to improve the output characteristic of microactuator mechanism, piezoeletric analysis was performed and the optimization model was built with w_b and α as design variables, the maximal output horizontal-plane displacement and the minimum vertical-plane displacement as objective. The final optimize result shows that the output horizontal-plane displacement of microactuator raises twice from 0.3µm to 0.6µm, meanwhile, the output vertical-displacement decreases from 0.093µm to 0.075µm by approximately 21 percent, the horizontal output characteristic has a remarkable improvement, so the optimal result can provide validity theoritical guidance for coming design strategy.

1. Introduction

Microactuator's function is to provide force or diaplacement output, it can transform other energy types such as electric energy, light energy, thermal energy into mechanical energy, so it has multiple different working principles and structural forms. Micro-electro-mechanical system(MEMS) consists of microactuator, microsensor, signal processing, control circuit, as the power source, microactuator plays an important role in micro-electro-mechanical system, its performance index directly impact devices' operational capability and efficiency, so it's important to obtain better output characteristic by optimizing sizes of microactuator. Piezoelectric microactuator has salient advantages such as it can produce large output force or displacement, quick response speed, high working frequency and control precision, etc[1,2] , so piezoelectric actuation is an ideal way to produce micro displacement, it has a great application potential in the future.

In this paper one new type piezoelectric microactuator with displacement magnification function was designed, the simple structure can be widely used in the internet things system to sense and drive.

2. Working Principle and Geometric Model of the Microactuator

The symmetrical structure of the microactuator is shown in Fig.1, it mainly consist of three parts, named as fixed port, central double-layer beam surrounded with rigid beam, and driving end. The upper layer of double-layer structure is piezoelectric membrane and the lower layer is made up of silicon, the elastic modulus and poisson ratio of silicon is respectively 179Gpa and 0.3. Size parameters of the microactuator are listed in table 1.

Based on the inverse piezoelectric effect, the working principle of the microactuator in horizontal-plane is once the positive and negative voltages is respectively applied on the bottom surface and the top surface, the central beam will bend up and down, and the deformation in plane will be produced in x direction, and the movement would be produced in y direction of rigid beam, thus driving displacement in plane would be produced. To improve the output displacement of the driving end in plane, the sizing optimization design[3-6] is performed with the software ANSYS Workbench.
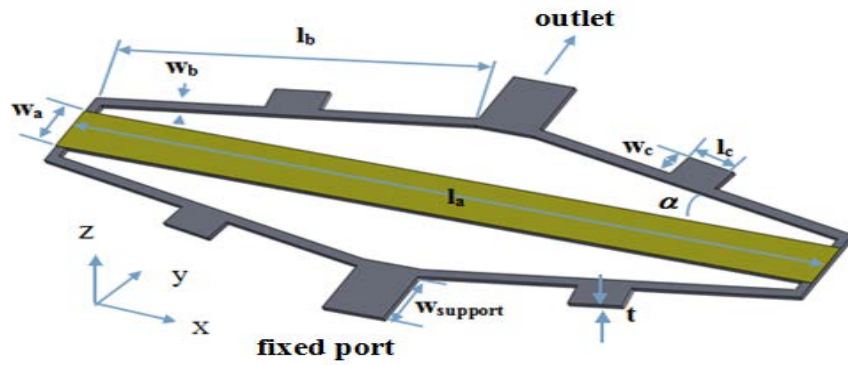
Fig.1 Geometric structure of the microactuator

Table1.Main parameters of the microactuator

Parameters	l_a [μm]	w_a [μm]	l_b [μm]	w_b [μm]	l_c [μm]	w_c [μm]	$w_{support}$ [μm]	α [°]	t [μm]
Dimension	1500	100	700	20	100	100	120	10	2

3. Optimal Design of the Microactuator

3.1. Initial Design Simulation of the Microactuator

FEM model of the microactuator is shown in Fig.2, the fixed port is constrained, the forces with the magnitude 7.26E-3N are applied on both sides of the central beam. The deformation in y-direction and z-direction of the microactuator is respectively shown in Fig.3 and Fig.4, it is shown that the largest deformation in y-direction happens at the driving end and the largest deformation in z-direction happens at the both ends of the microactuator, and the displacement of the driving end in y-direction and z-direction is repectively 0.3µm and -0.093µm.
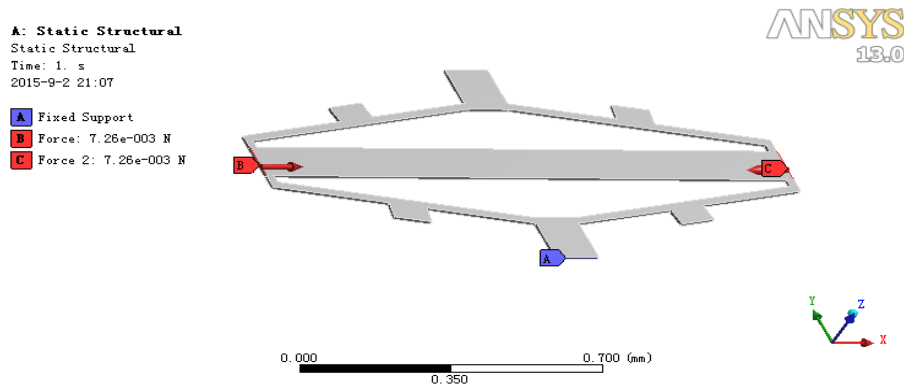

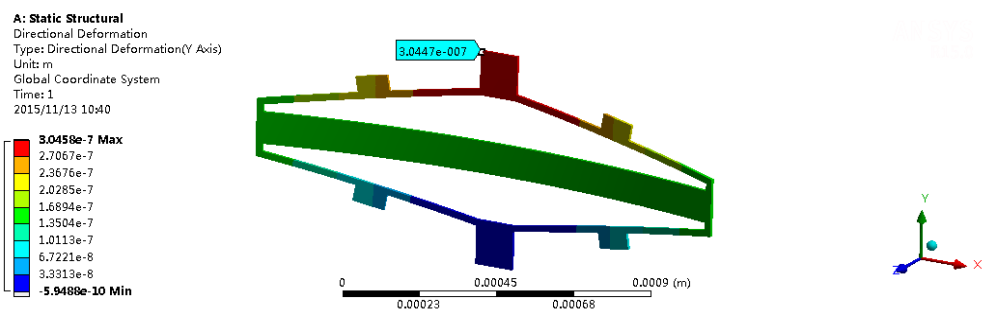Fig.2 FEM model of the microactuator

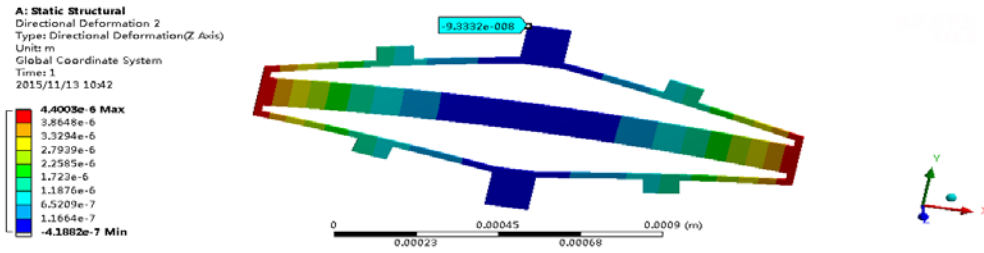Fig.3 Y-direction displacement of microactuator

Fig.4 Z-direction displacement of microactuator

3.2. Mathematical Optimization Model of the Microactuator

The role of the microactuator is to provide as large y-diretion displacement as possible, and an overlarge z-diretion displacement has a seriously adverse effect on the horizontal output characteristic of the microactuator, so the capability to provide y-direction displacement in the driving end is the most important indicator of the microactuator, thus, the maximum output y-diretion displacement should be chosen as the objective, in addition, the z-direction displacement of the driving end should be as minimal as possible to keep the functional planarity. A multi-objective model is built to obtain maximum y-direction displacement and minimum z-direction displacement on the driving end of the microactuator. The optimization numerical model is shown below:

$$\begin{cases} \max & u_y(w_b, \ \alpha) \\ \min & |u_z(w_b, \ \alpha)| \\ s.t. & w_{bl} \leq w_b \leq w_{bup} \\ & \alpha_l \leq \alpha \leq \alpha_{up} \end{cases}$$

Where:

u_y — y-direction displacement of the driving end

u_z — z-direction displacement of the driving end

w_b — the width of the rigid beams

α — the angle between the rigid beams and the central beam

w_{bl}, w_{bup} — the lower and upper limit of the design variables

α_l, α_{up} — the lower and upper limit of the design variables

3.3. Sensitivity Analysis and Optimization

The sensitivity analysis is performed with the design variable w_b and α respectively belonging to 10~30µm and 0.1°~5°. The 25 groups of design points are automatically generated with the method of Central Composite Design in ANSYS Workbench, the sensitivity analysis result is shown in Fig.5, it can be concluded that the angle between the rigid beams and the central beam (α) has a greater effect on the displacement in y-direction and z-direction of the driving end, in addition, the width of the rigid beams (w_b) has a comparatively less effect on displacement in both of y-direction and z-direction of the driving end. The structural response cuve (Fig.6) is extracted, and the relationship between the output displacements and design variables can be seen from it.

As shown in Fig.6(a), the output displacement in y-direction increases with the angle α increasing from zero to 5°, and then decreases with α increasing, the maximum value happens at the point with angle about 5°. From the Fig.6(b), it is shown that the minimum displacement of u_z happens at the point with angle about 16°, the z-diretion displacement value reduces to 0 approximately with the angle 16°. It can be seen from the Fig.6 (c) and (d) that the displacements of u_y and u_z decrease with w_b increasing, it is due to the stiffness of the structure is increased with w_b increasing.
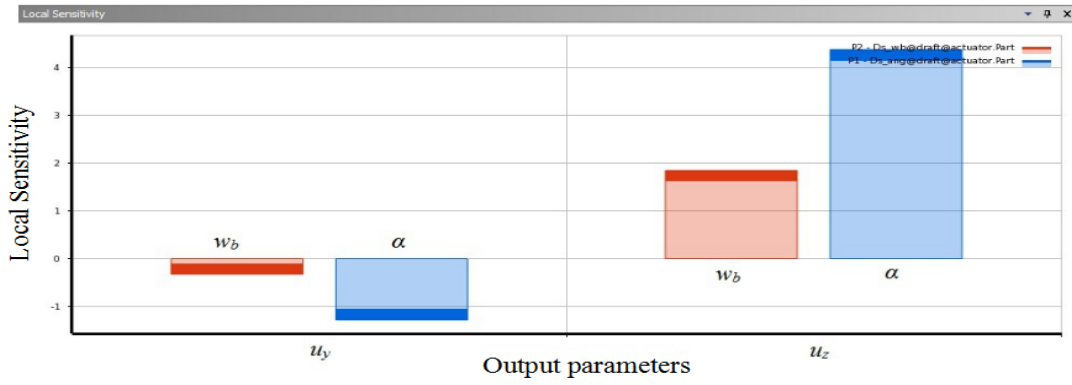
Fig.5 Sensitivity analysis histogram

(a) Relationship between α and u_y

(b) Relationship between α and u_z

(c) Relationship between w_b and u_y
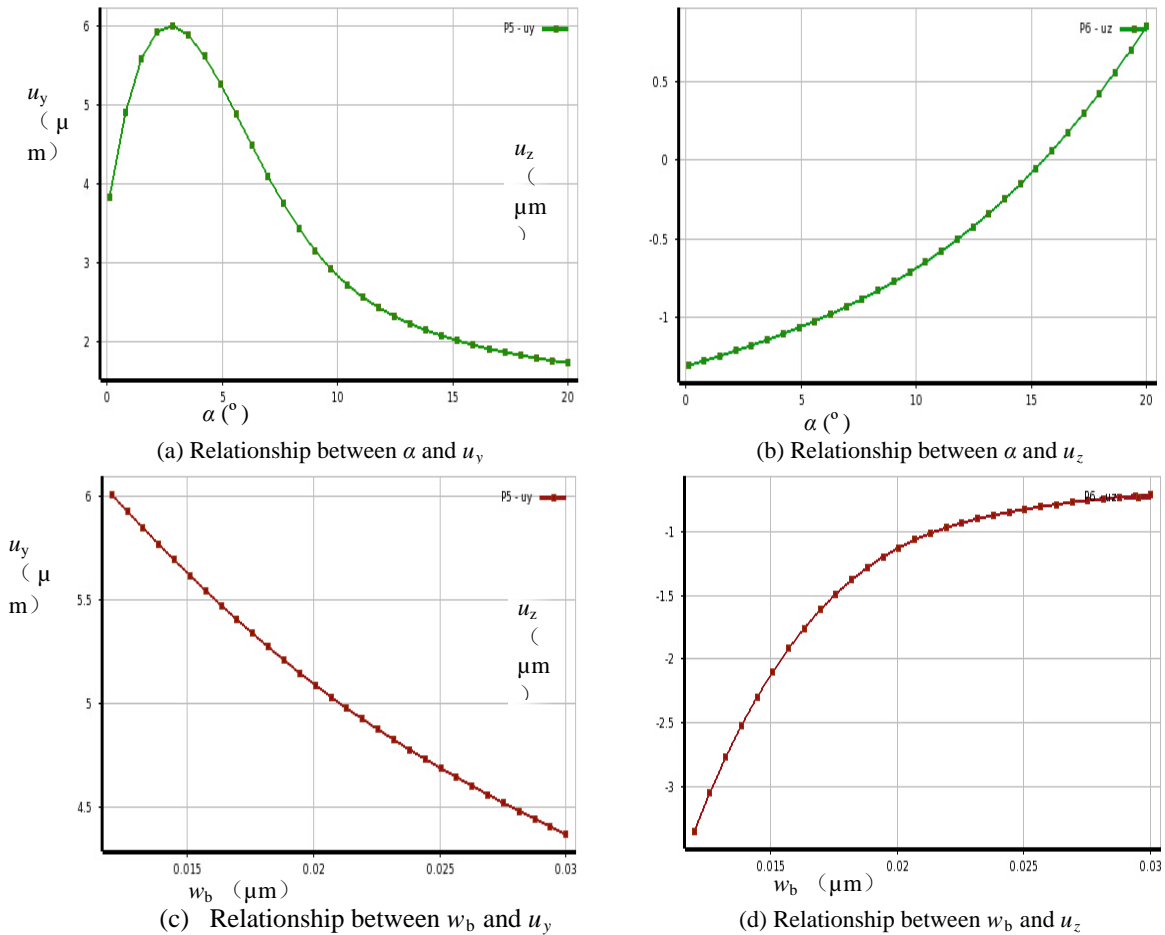

(d) Relationship between w_b and u_z

Fig.6 The relationship between the output displacements and design variables

The optimization model is solved with DOE method (Design of Experiment), with the maximum displacement in y-direction, the minimum absolute value of output displacement in z-direction $|u_z|$ chosen as objectives, three final candidate results are listed in table 2. Compared with the original design result, the displacement of the driving end in y-direction has a remarkable improvement from 0.3μm to 0.72μm by about 140 percent in the optimal design 1, however, the displacement of the driving end in z-direction is also raised significantly from 0.093μm to 0.14μm by about 47.4 percent. From the optimal design 2, it is shown that the displacement in y-direction increases remarkably from 0.3μm to 0.6μm by about twice and the displacement in z direction decreasing from 0.093μm to 0.075μm at the same time, the result of optimal design 3 shows that the displacement in y-direction has a less improvement. For the optimal design 2 in table 2, by comparing with the results of optimal design 1 and 3, it has a better horizontal output characteristic, so the optimal result is fairly good. Consequently, the design variables parameters of optimal design 2 in table 2 can be chosen as the final optimal design combination of the microactuator. The angle value between the rigid beams and the central beam (α) should be chosen 4.2º and the width value of the rigid beams

(w_b) should be chosen 19μm.

Table.2 Comparison of optimal design with original design

	α [°]	w_b [μm]	u_y[μm]	$/u_z/$[μm]	u_y variation	$/u_z/$ variation
Original design	10	20	0.3	0.093		
Optimal design 1	2.2	16.7	0.72	0.14	140% increase	47.4% increase
Optimal design 2	4.2	19	0.6	0.075	100% increase	21% decrease
Optimal design 3	6.1	19.2	0.47	0.07	56.7% increase	26.3% decrease

Conclusions

To acquire the maximum displacement in y-direction and minimum displacement in z-direction, the optimization technology is used. The multi-objectve optimization model is built with the width w_b of the rigid beams, and the angle α between the rigid beams and the central beam as design variables. The sensitivity analysis and optimization are performed. Results show that the displacement in y direction and z direction is greatly affected by width w_b and the angle α, the optimal displacement in y direction doubles the original design from 0.3μm to 0.6μm, meanwhile the displacement in z direction decreases from 0.093μm to 0.075μm. The optimization method is proved effective and has a certain instructional significance to engineering design.

Acknowledgements

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