DECOUPLING OPTIMIZATION OF FLEXURE HINGE AND LEVER MAGNIFYING MECHANISM FOR AN XY COMPLIANT MICROMANIPULATOR

Xiaohui Xiao, Lizhi Pan, Xuemei Tong
School of Power and Mechanical Engineering, Wuhan University, Wuhan, 430072, China

Introduction

The micro/nano motion stage with ultra-high precision are urgently required to perform such tasks as operation under scanning probe, bio-cell manipulation, optical fibers alighment, etc. The compliant XY micro manipulator employing flexure hinges is widely applying due to their excellent characteristics of simple structure, no backlash, no nonlinear friction, and so on [1]. Some novel compliant parallel manipulators are designed to suppress the coupling of motion of multi manipulation DOP [2, 3]. However, balance of decoupling and magnifying ratio of lever mechanisms is still one of the critical points for designing.
Concerning the compliant XY micro manipulator having flexure hinges and lever mechanisms with piezo-driven actuators, aiming at optimal performance of as large magnification ratio and little coupling, the paper applied measures to the original stage. FEM analyses in ANSYS were performed to verify the minimum parasitic motion effects and guarantee the workspace, which just validated the assumptions.

Structure Optimization

When developing an XY micro-motion stage with flexure hinges, which realizes the long stroke through levers, it's essential to reduce the coupling between X and Y direction motion and thus to make the control of the motion easier. On the other hand, the effective ratio should be increased as much with a certain theoretical magnification ratio which is limited by the size of the stage. Both the qualities above are cores to the design of stages of this sort.
Here presents an XY micro-motion stage with features of flexure hinges. Levers are adopted to magnify the displacement and enlarge the stroke. See Table I for relevant parameters of the stage, Fig.1 for original structure.

Table 1 Parameters of the XY Stage

Items	Parameters
Stroke	20um
Workspace	60*60mm
Magnification	3.0
Critical frequency	400Hz

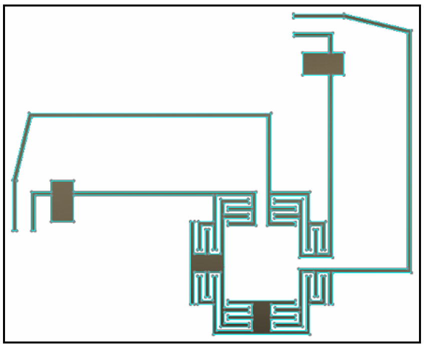


Fig.1 The original micro-motion stage

In order to minimize the parasitic motions and satisfy the performance specifications, a series of measures have been taken trying to gain an optimal stage with much less coupling and larger magnification.
1) Reducing the coupling
a) Decreasing the unsymmetrical rigidity caused by the levers is necessary to reduce the coupling.
Symmetrical arrangement of the X and Y direction levers as illustrated in Fig.2 is proved helpful to relieve the parasitic motion of the stage.
Besides, it enables a good balance of the unsymmetrical stiffness to enhance the rigidity of the flexure hinges across the X and Y levers. See Fig.3 for intuitionistic view.

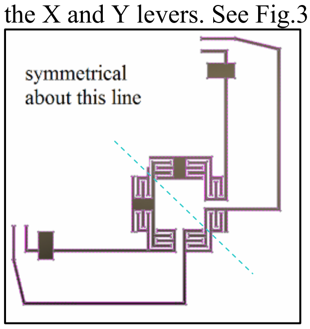


Fig.2 Symmetrizing the levers

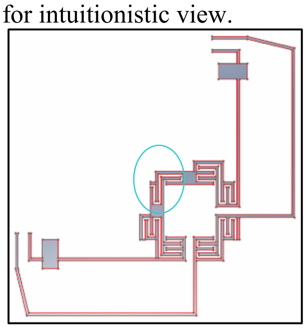
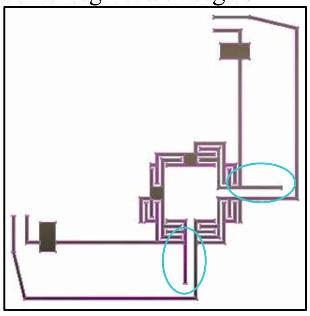


Fig.3 Enhancing marked hinges

b) Decreasing the stiffness of the parasitic motion direction while ensuring that of the actuated direction is evidently good for decoupling.

As the most effective method, slotting in right place as shown in Fig.4 can remarkably reduce the coupling as well as increasing the magnification..
Adding round corner can also help to relieve the coupling to some degree. See Fig.5.



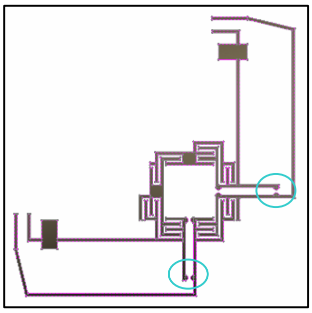


Fig.4 Slotting to isolate motions   Fig.5 Adding round corners

The measures abovementioned are also found positive to increase the amplification due to the active control of reducing the coupling.

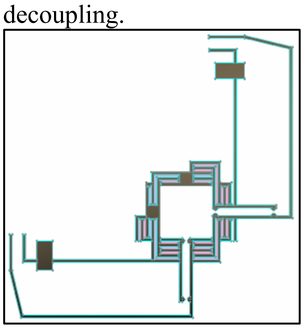
2) Increasing the magnification

Appropriate stiffness of the lever and the flexure hinges is helpful to balance the statics and dynamics of the stage.

a) Decreasing the stiffness of the flexure hinges can enlarge the magnification but reduce the critical frequency and thus affect the working bandwidth.

As described in Fig.6 and Fig.7, adding the actual length of the flexure hinge by increasing the layer amount of wheels is available and it's advisable to change the thickness of the hinge tip width from 1mm to 0.5mm so as to reduce its stiffness.

b) Enhancing the rigidity of levers has a positive effect on enlarging the magnification but is negative for the motion decoupling.



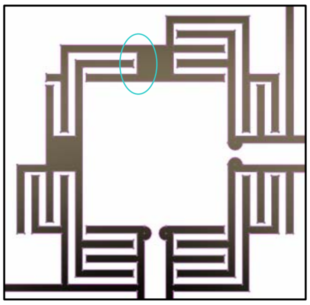


Fig.6 Lengthening the hinges   Fig.7 Decreasing the tip width

Simulation and Performance Evaluation

The original design and optimized structure are respectively depicted from Fig.1 to Fig.7, while by resorting to ANSYS static analysis, simulations are performed to preview different properties of the stage before and after the modifications. Table Ⅱ indicates the relative output in detail with the same input displacement of 0.02mm.

As it is shown, all the design requirements have been met in the end with rather large improvement on the magnification and decoupling performance, which have remarkably increased from 2.17 to 3.31 and decreased from 0.88 to 0.018, respectively.

Table 1 Performance of the Stage

Stage	Direction	Magnification	Coupling factor	Critical Frequency
Fig.1	x	2.16675	-0.283742933	494.46
	y	2.4131	-0.887862086	
Fig.2	x	2.2217	0.866813701	458.47
	y	-2.1925	0.878540479	
Fig.3	x	1.76175	0.872357031	502.71
	y	-1.7487	0.865128381	
Fig.4	x	2.5299	0.311039962	464.54
	y	-2.5993	0.29752241	
Fig.5	x	3.0348	-0.096019507	480.71
	y	-3.15585	0.100012675	
Fig.6	x	3.19665	0.073639591	412.12
	y	3.2279	-0.081492611	
Fig.7	x	3.3135	0.013074393	362.37
	y	-3.3123	0.018147511	

Conclusion

The structure improvement and dimension optimization are carried out in details in this paper, which involves rearrangement of levers, stiffness modification of hinges and addition of block zone against parasitic motion. In a sense, it results in a new stage with much better performance and the FEA results have validated the assumption.

The measures in this paper are proved beneficial attempts for the design of micro-motion stages likewise and theoretically helpful as well.

References

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