Proceedings of ICAD2004
The Third International Conference on Axiomatic Design
Seoul – June 21-24, 2004
ICAD-2004-40

DESIGN IMPROVEMENT IN A MICRO-GRIPPER SYSTEM BY AXIOMATIC APPROACH

Jeon, Jonghyup.
hyup@postech.ac.kr

Wonkyu Moon.
wkmoon@postech.ac.kr

Jongkyu Park.
chong@postech.ac.kr

Vibration and Acoustics Lab.
Department of Mechanical Engineering
Pohang University of Science and Technology
Hyoja-dong San 31, Pohang 790-784
KOREA

ABSTRACT

The micro-gripper system is one of the systems that should be improved in the respect of performance for practical usage. In the previous works, the important issues are considered and presented using axiomatic design approach. In this paper, the functional requirements and design parameters are evaluated in order to improve the performance and efficiency of the system. The evaluation is a very difficult task since many variables are related to the outcomes. To provide a basis for correct design decisions, axiomatic design principles have been advanced. Since the framework of axiomatic design makes design issues easier to understand when they are analyzed, we used those as an evaluation tool.

The object of the system is to handle micro-size parts. Main device is a micro-gripper using two bender-typed and one stack-typed PZTs as actuators. And it has three tips made of tungsten wires for holding function. Also the system must satisfy other functional requirements for appropriate handling performance.

The results of this study show design improvements of micro-gripper system such as structural change of gripper, additional element, and integration of physical parts. Axiomatic design guides presented suitable design parameters corresponding to functional requirements and made the design elements improve through diagrams of whole system.

Keywords[1]: Design, Axiom, Micro-gripper

1 INTRODUCTION[2]

The axiomatic design principle is a systematic and rational method for the design based on two axioms, the independence and the information. So those require conditions that the functions of the design be independent each other, not the physical part, and the physical integration is desirable to reduce the information contents. The first axiom gives the appropriate relations between functions and design parameters by schematically hierarchical structure. And the second axiom gives a criteria selecting the optimal thing among the options corresponding to functional requirements through the statistical examinations. So actually this principle can be applied to all round fields in respect of the design including that of manufactures like machines. Especially approaching procedure takes advantage of the establishment and settlement of any problems in the designed system because of using clear and logical ways. And the various applications for manufactures and processes have verified the usefulness in the respect of the design. [1,4,5,6]

The paper presents an application to the design for a mechanical system of axiomatic design principle. First of all the goal is the evaluation of existing system by the principle. Second of all the improvement of the system and the verification of the effectiveness of axiomatic design theory are expected.

The system concerned here is the existing micro-gripper system.[2] It is composed of subsystems for functions as holding, moving, releasing, and viewing when manipulating the micro-size parts. The production and operating test of the system as the first generated model have been already finished. And then some problems to be solved are exposed through the tests.

Now for the reconstruction and improvement of the system, the problems have to be classified and the ideas to solve are needed using the axiomatic design method. Also the devices to materialize them must be found.

From this point of view, this research follows the general procedure of the axiomatic design. In other words, at first the functional requirements(FRs) are set up, and then the suitable design parameters(DPs) are presented considering the constraints. The next step is to check reasonability of the decided FRs and DPs according to the axioms. This processes have to be tried repeatedly for the more reasonable and suitable final design.

2 THE EXISTING MICRO-GRIPPER SYSTEM

2.1 MICRO-GRIPPER

In the whole system, the main part is the gripper that performs the functions of holding and releasing. This gripper will be improved to be able to manipulate bio-materials finally. The gripper to be evaluated by the axiomatic design principle corresponds to a prototype model.

Since the current research for the micro-gripper is actively progressed, the fundamental functions required as a system are widely known. That means the functional requirements are set in the respect of axiomatic design. The actuators of gripper have to be controlled to exert appropriate force to hold but not to hurt the objects. Also it is available for various objects and at the instant of movement, the structural stability must be guaranteed. Especially the vibration problem after moving will a main target solved in our system through the new design. And surface effects like electrostatic force, surface tension, van der Waal's force are the serious problems to disturb releasing functions.

The kinds of gripper are diverse.[2] According to the types of actuators, they can be divided into mechanical type using piezo-material or shape memory alloy, adhesive type using the viscosity of fluid, and absorption type using electrostatic force or pressure difference. Among them we will treat the gripper with 3 piezo-material actuators. (PZT actuators)

The PZT actuators of the bender type show the suitable properties to deal with micro-parts as the strong enough force for holding, the precise actuation of high resolution(0.1um) and besides the relatively large stroke (over 100um).

2.2 MICRO-GRIPPER SYSTEM

The whole micro-gripper system consists of 5 subsystems by the functions. If the system is considered as the view point of axiomatic design, it can be expressed by a diagram, Figure 1. Then FRs and DPs must be decomposed into a hierarchy until the design is completed through zigzagging.

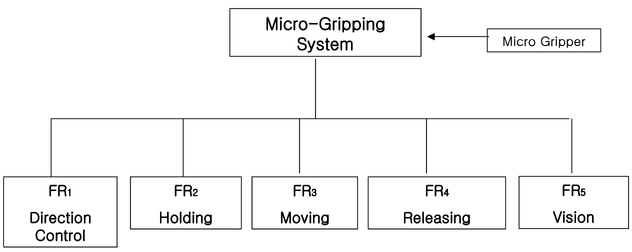

Figure 1. First layer of the hierarchical diagram for micro-gripping system.

2.3 DIRECTION CONTROL FUNCTION

For the large working range and easy access to the object, several micro-stages creating the multi-degree of freedom are used.

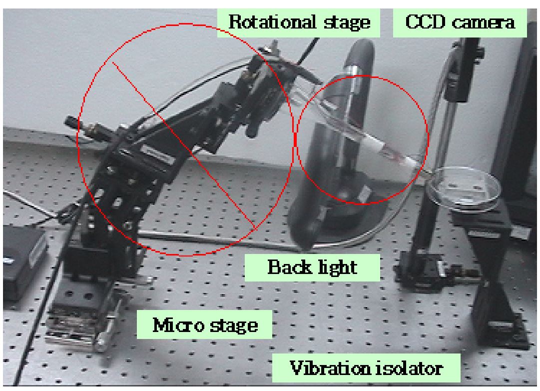

Figure 2. Subsystem to control direction using micro-stages

2.4 HOLDING FUNCTION

This function is performed by micro-gripper of 3 chopsticks type with 3 PZT actuators and 3 tungsten wire tips. The structure is shown in Figure 3. One PZT actuator of the stack type is used to arrange to meet the endpoints of tips. And the operations for gripping and stabilizing sequentially are carried out by other PZT actuators of bender type.

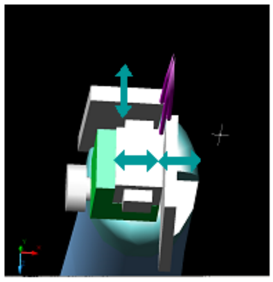

Figure 3. Design view to show actuating directions of each actuator in the gripper

2.5 MOVING FUNCTION

Micro-manipulator shown as Figure 4 beside micro-stages for moving is useful in precise and easy control by automation. It gives a larger moving range compared with micro-stages by hand operation but needs additional actuators and controllers.

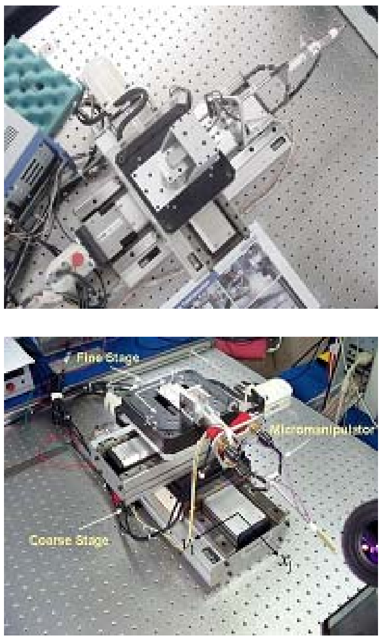

Figure 4. Subsystem to perform moving function

2.6 RELEASING FUNCTION

Releasing is the reverse function of holding. So operation is established by reverse process. However the operation removing the surface effects by the remaining adhesive forces must be added for completely releasing micro-part from tips. So the structural design to cause point contact of sharp tips' endpoints help the adhesion by van der Waal's force decreased. Also through discharging free charges by grounding tips of gripper, electrostatic force can be reduced.

2.7 VISION FUNCTION

Vision system is essential for treating micro-parts because they are not visible to the naked eye. So shown as Figure 5, the system of 2 CCD cameras and 1 optical microscope is created.

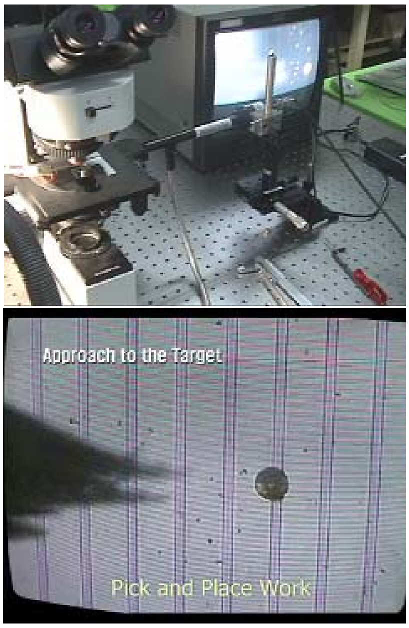

Figure 5. Test view through the CCD monitor

3 THE IMPROVED MICRO-GRIPPER SYSTEM

3.1 PROBLEM ANALYSIS AND IMPROVEMENT PLAN

By applying the axiomatic design principle, improved DPs corresponding to improved FRs are settled for the stable and precise operation through zigzagging. The uncoupled design is made by inspecting the relations between them in the last analysis.

3.2 CONSTRAINTS

The constraints for fabrication and cost are neglected. But the scales of each part are well considered for whole system in the respects of manufacture and operation And since the feedback control is inevitable for accurate operation, the coupled design will be included.

3.3 IMPROVEMENT (1)

In the system, the highest level FRs and DPs are decided by sequential considerations of operating processes. However the deduction of integration of physical parts in the information axiom makes unnecessary FR(FR1) certificated. In result shown as Figure 6, DP1 and DP3 are integrated into a physical part and FR1 can be removed.

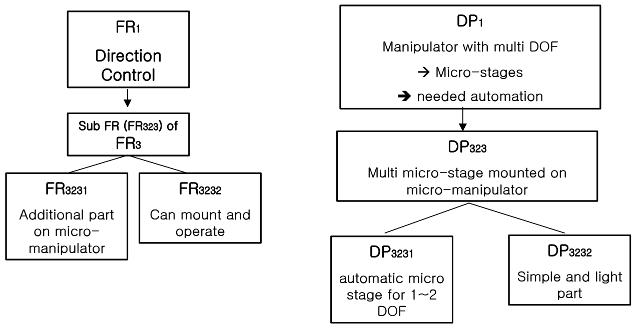

Figure 6. Hierarchical diagram for direction control function

3.4 IMPROVEMENT (2)

The initialization of one point contact among 3 endpoints of tips is required for exact operation of holding function. It is conformed by test of prototype model. So the supplementary parts named calibrator are suggested and designed easily arranging endpoints as a simple structure in the connecting position of tips and PZT actuators. And the mechanism of feedback control is proposed to exert the suitable force corresponding to material property of objects in the holding operation. These additional design elements are presented in the Figure 7.

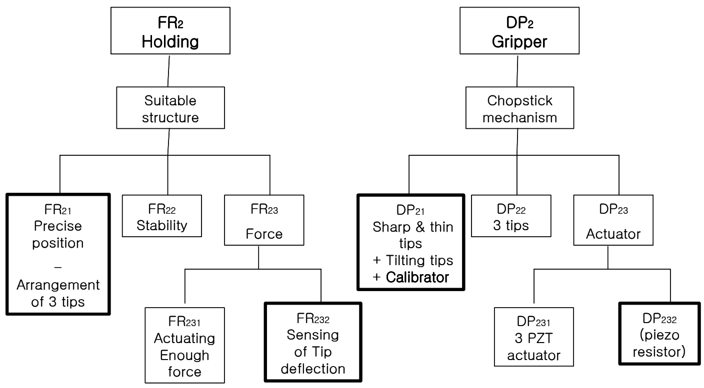

Figure 7. Hierarchical diagram for holding function

3.5 IMPROVEMENT (3)

The vibration of the tip after moving is conformed as a significant problem solved in the operation test. Although at first a solution by feedback control is suggested, it is too difficult to be actualized. Therefore another way is devised to reduce the vibration through the modification of structure. In result the design is changed that the length of gripper arm is shortened so robust structure for vibration at low frequency is made. And this part is considered by physical integration with direction control function(FR1). These improvements are shown as Figure 8.

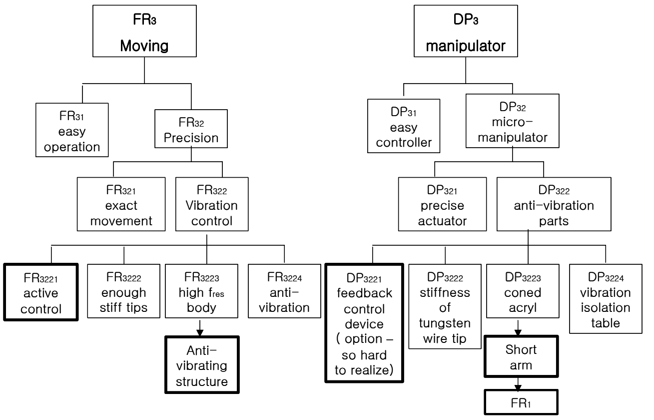

Figure 8. Hierarchical diagram for moving function

3.6 IMPROVEMENT (4)

Through the operation test, it is checked that existing ways are not sufficient to release micro-parts from the tips. So an active method is suggested to use repulsive forces of electrostatics. (Figure 9) But the possibility is not yet certificated.

The modification of vision system is necessary to be easily operated. (Figure 10)

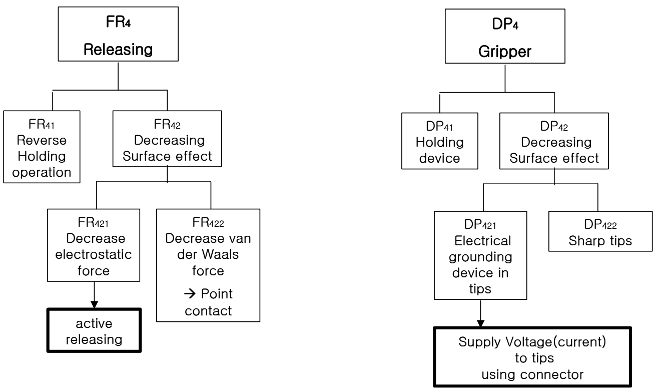

Figure 9. Hierarchical diagram for releasing function

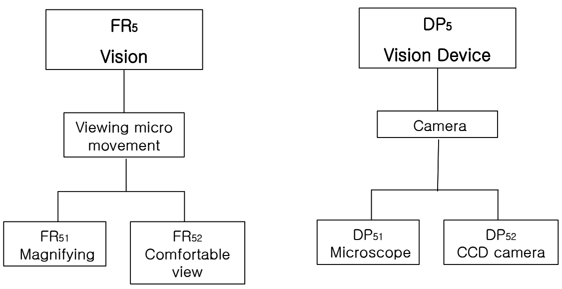

Figure 10. Hierarchical diagram for vision function

3.7 IMPROVEMENT RESULT

The formation of the existing whole system is shown as Figure 11. The new system are expected to reduce the problems detected by application of axiomatic design theory. At last the improved model will be looked for higher performance and less physical parts.

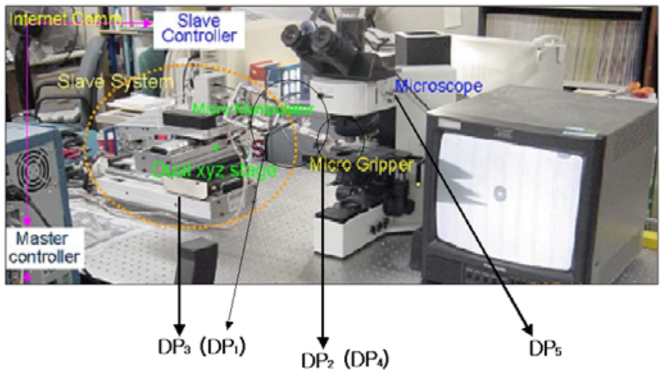

Figure 11. Organization of existing gripping system

Figure 12 shows the master matrix for FRs and DPs of the improved whole system. We can conform that except for the unavoidable coupled section by feedback control, the design is uncoupled in the last analysis.

	DP_1	DP_{21}	DP_{22}	DP_{231}	DP_{232}	DP_{31}	DP_{321}	DP_{3231}	DP_{3232}	DP_{3221}	DP_{3222}	DP_{3223}	DP_{3224}	DP_{41}	DP_{421}	DP_{422}	DP_{51}	DP_{52}
FR_1	X											X						
FR_{21}		X																
FR_{22}			X															
FR_{231}				X	X													
FR_{232}				x	X													
FR_{31}						X												
FR_{321}							X											
FR_{3231}								X		x → o	x → o	X → x	x → o					
FR_{3232}									X	x → o	x → o	X → x	x → o					
FR_{3221}										X								
FR_{3222}											X							
FR_{3223}												X						
FR_{3224}													X					
FR_{41}														X				
FR_{421}															X			
FR_{422}																X		
FR_{51}																	X	
FR_{52}																		X

Figure 12. Master design matrix for modified total system

Figure 13 is the flow diagram to grasp and inspect the organization of the whole system. Especially the feature that the blocks of modules can not be crossed each other gives an important modification in the new design decomposition. It is certificated that it is useful for the design of complicated system.

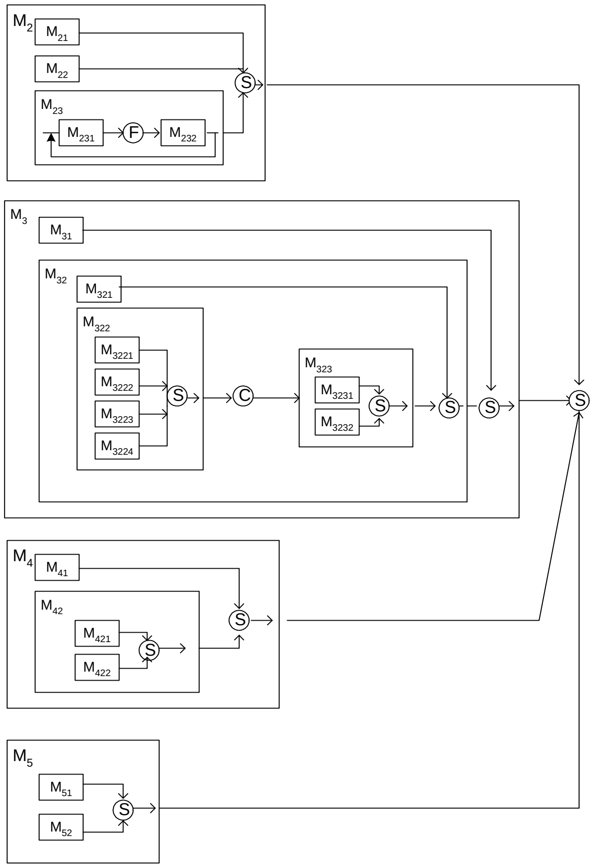

Figure 13. Flow diagram for modified total system

4 CONCLUSIONS

The evaluation and improvement for existing product (micro-gripper system) were tried using the axiomatic design theory. The presented new design are expected to have higher performance and less physical parts. And it is verified that the axiomatic design theory gives effective processes to find and solve the problems through hierarchical structures.

In our research, the reasonability and the usefulness of the axiomatic design principle is checked for the case of a mechanical system.

5 REFERENCES

[1] N.P. Suh, *Axiomatic Design Advances and Applications, Oxford University Press*, 2001. ISBN 0-19-513466-4

[2] J.K. Park, "Systematic Design and Fabrication of a Three-Chopstick Microgripper," Accepted for publication in International Journal of Advanced Manufacturing, 2002.

[3] N.P. Suh, *The Principles of Design*, New York: Oxford University Press, 1990. ISBN 0-19-504345-6

[4] N.P. Suh, "Designing-in quality through axiomatic design," IEEE Trans Reliab, 1995.

[5] S.J. Kim, N.P. Suh, S.K. Kim, "Design of software systems based on axiomatic design," Ann CIRP, 1991.

[6] B.S. Jang, "Axiomatic design approach for marine design problems," Marine Structures, 2002.