# Constant-Force Compliant Gripper Mechanism


## Abstract

The project proposes to model, design and experimentally test several constant-force compliant mechanism grippers that can be used for precision robotic manipulation. Compliant mechanisms use flexure hinges (which are slender, flexible portions that can bend and enable relative rotation between rigid links) instead of classical translation and rotation joints. These devices are very modern and significant research efforts are currently dedicated to flexure-based compliant mechanisms, particularly with applications to micro/nano electromechanical systems (MEMS/NEMS) and precision positioning devices. The goal of this project is to design compliant grippers by amplifying an input motion from a linear actuator and to create a constant output force, which would enable grasping of objects having various dimensions through application of the same gripping force. Both amplification and constant force output will be created through design by selecting the proper geometric configuration. A constant force output for different displacements will be achieved by the change of the length and therefore the stiffness of the gripper arms. Various gripper designs will be studied and modeled with Solid Works or AUTO Cad and then analyzed with the finite element analysis software ANSYS. After finding the optimal geometry for an adequate amplification and, more importantly, for a constant force output, a planar compliant gripper will be fabricated. Furthermore, a force sensor will be modeled, designed and fabricated to perform force tests with the gripper prototype. This sensor will also be based on compliant mechanism. Both the gripper and the force sensor designs will be sent as drawing files to the company which will fabricate these mechanisms by electric discharge machining (EDM). The fabricated gripper will then be tested in the School of Engineering's labs at UAA by using the compliant force sensor as well as other sensors which are already available in the Engineering labs or the sensors which will be acquired through this project.

## Previous Work

In the Fall 2007 semester I took the Course ME 302, Mechanical Design I at UAA with Dr Lobontiu, my mentor with this proposal. In the lab, groups of 3-4 students worked on a project which focused on compliant mechanisms. In the lecture of Mechanical Design I Dr. Lobontiu introduced the concept and explained the advantages and disadvantages of Compliant Mechanisms. My group designed a grabber which was drawn with Solid Works. Introduced in this course were also the main features of the CAD software Solid Works and the finite element analysis tool Cosmos, which is part of Solid Works. With this introduction and my experience with Solid Works I gained in an "Introduction to Construction" class I took in Germany, we modeled the grabber, analyzed its stresses (Figure 1) and displacements (Figure 2).

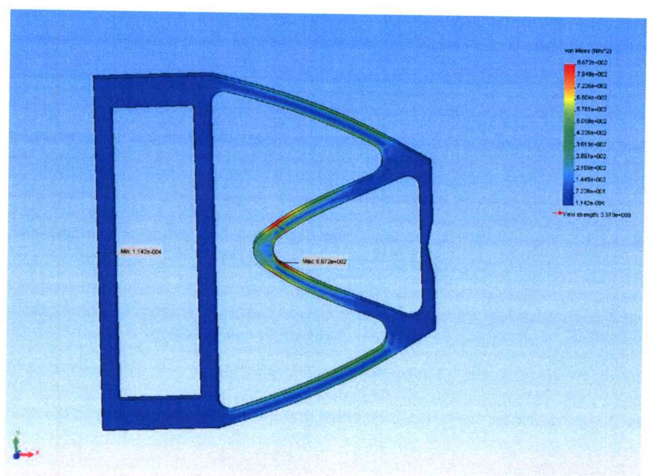

Figure 1. Grabber stress analysis

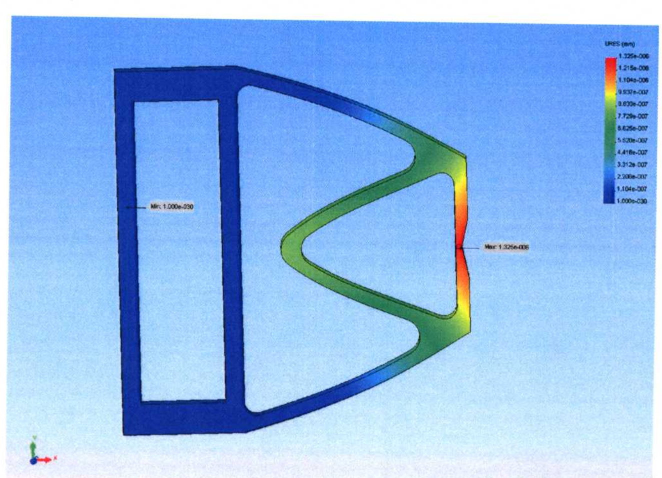

Figure 2. Grabber displacement analysis

Furthermore, during an internship in Germany I worked with Inventor, a three-dimensional (3D) modeling program which is similar o Solid Works. At the University of Furtwangen, Germany I took the class Technical Mechanics 3 where I learned to use the finite element analysis tool ANSYS, which will be employed to do the analysis of this project.

Dr. Lobontiu's expertise in the topic of Compliant Mechanisms (where he has published several books and journal papers) will be of great support to me in completing the tasks of this project. In addition, I will be able to use some equipment that was recently acquired at UAA which will enable me to conduct the experimental testing section of this project.

## Introduction

The proposed research intends to study a class of Compliant Mechanisms that are designed to produce a constant output force and an amplification of the input motion. The grippers are implemented in a lot of applications where precise manipulation combined with grasping of an object need to be performed, such as in microelectronics, telecommunications or micro and tele (distance) surgery. Although the current state-of-the-art research looks at various compliant grippers (particularly for MEMS applications), there is a limited focus on constant-force compliant grippers (which have the major advantage of being insensitive to the dimensional range of the grasped objects), which is the object of this proposal.

The main difference to classical linkages that use rotation and translation joints is that compliant mechanisms have flexible portions, generally known as flexure hinges. These hinges undergo elastic deformations – usually of bending or torsion – which enable the relative motion between rigid links. The principal advantages of compliant mechanisms are their compactness, no need for assembly (because the adjacent links are monolithic), no maintenance, no friction losses, and precise motion. Figure 3 shows a corner-filleted flexure hinge connecting two adjacent rigid members.

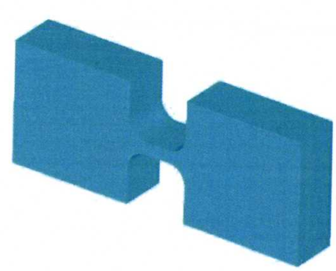

Figure 3. Corner-filleted flexure hinge

Analytical models of various flexure hinges have been developed by Paros and Weisbord [1] (circular flexure hinges), Smith et al. [2] (elliptical flexure hinges), Lobontiu et al. [3] (corner-filleted flexure hinges, as the one shown in Fig. 3) or Lobontiu et al. [4] (conic-section flexure hinges such as parabolic and hyperbolic). The monograph by Lobontiu [5] offers comprehensive information on various flexure hinges and flexure-based compliant mechanisms. Similarly, the monographs of Howell [6] and Smith [7] present mostly descriptively topics of compliant mechanisms and flexure hinges.

Compliant grippers offer the advantage of smoothly applying the grasping force to an object whose position needs to be changed through manipulation. Most often, compliant grippers are designed with two finger/jaw-like prongs that capture an external object, but hand-like grippers with several prongs are also an option.

The photograph of a compliant, flexure-based gripper prototype is shown in Figure 4 below, whereas Figure 5 is the schematic representation of the equivalent gripper with classical rotation and translation joints.

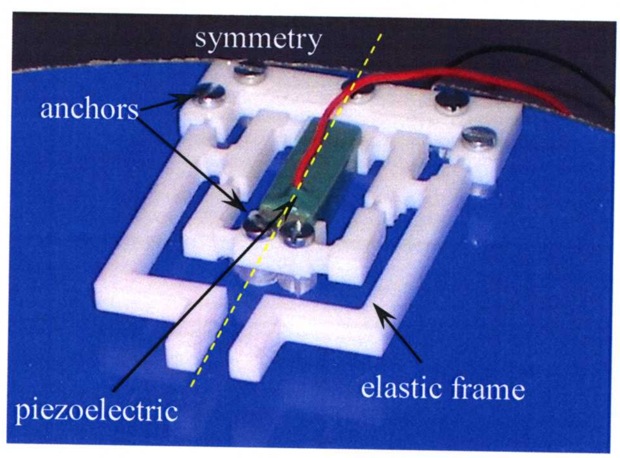


Figure 4. Photograph of a flexure-based, piezoelectric-actuated gripper

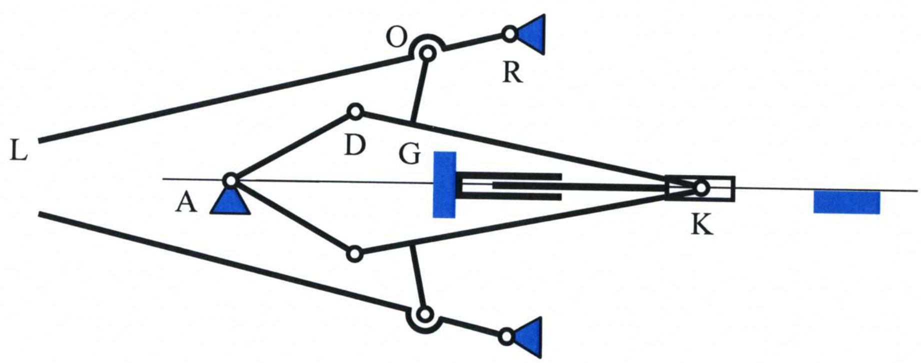


Figure 5. Representation of gripper with classical rotation/translation joints and linear actuator

The current research mostly focuses on two-prong grippers that have been designed and tested to produce grasping through planar motion and deformation of their compliant segments under piezoelectric actuation – [8]-[14] for precision macroscale manipulation. In many instances, the jaw motion is rotational and results in non-parallel displacement of the two prongs, similar to the motion of a human hand finger motion – [11]-[14]. Designs have also been reported where the jaws undergo parallel motions before grasping the object to be manipulated – [8]-[10]. Multi-fingered compliant grippers ensure more firm of a contact/grasp whereby each finger is driven individually by a linear (either piezoelectric or shape memory alloy) actuator – [15], [16]. Microgrippers for microelectromechanical system applications have also been reported being built and tested by employing flexure-based compliant frames and thermal or electrostatic actuation [17]-[19].

## Project Proposal

There are several applications for constant force outputs. Examples are electronic connectors that maintain a constant force regardless of part tolerances, constant force springs in a hospital bed, gripping device for parts of varying size, and manufacturing processes that involve tools with different diameters. Constant force mechanisms will produce a constant output force for a certain range of input displacement. Usually the output force increases linearly with the displacement like in the case of a spring where the force can be determined with the equation:

$$F = k * s$$

where k is the spring constant and s is the displacement. By using compliant mechanisms with specific geometry and stiffness it is possible to produce a constant output force for various displacements.

There are several other ways to achieve a constant force output. One of them is the use of shape memory alloy. When one bents the alloy, the force will increase linearly with the deformation in the beginning. After reaching a certain displacement, the force will remain constant for any further deformation. This principle could be used for the design of a gripper. Another principle is the use of spring like the ones shown in Figure 6, [20].

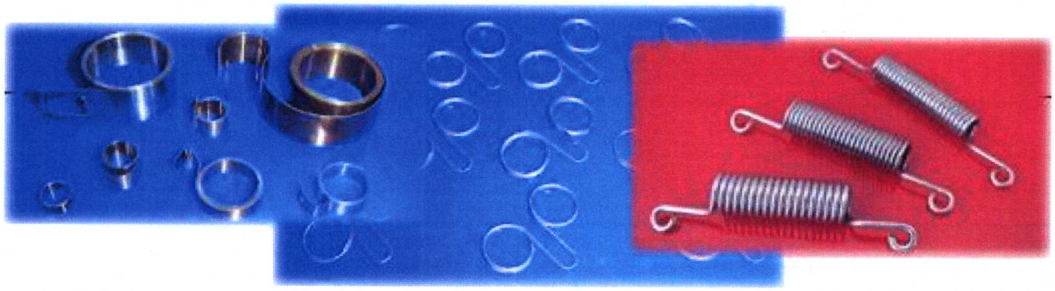

Figure 6. Constant force springs

The stiffness of the material changes since the length of the piece that is bent gets shorter. This is another way to achieve a constant force output. The same concept will be used in this project. Through a special shape of the rounded feature in the gripper shown in Figure 7 it is possible to change the stiffness of the arms of the gripper and achieve therefore a constant force output. This shape has to be determined with finite element analysis. When a force applies to a flexure, as shown in the left of Figure 7, a larger portion of the flexure root will get in contact with the rounded support and will therefore change the actual length of the flexure (and therefore its stiffness).

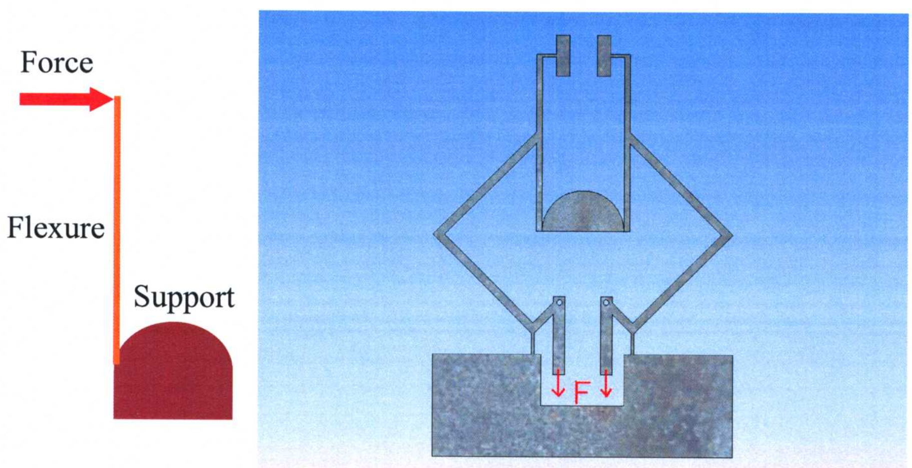


Figure 7. Constant-force compliant gripper design

Furthermore, an amplification of the input motion needs to be achieved. The big advantage of this gripper is the easy control of the output force because the input displacement doesn't have to be as accurate since the output force does not increase with the displacement. In addition, the flexible arms of the gripper ensure that the maximum force output is not very large since they will bend if the pressure on the piece that is being held by the gripper becomes too large. Therefore the grasped object integrity will not be in jeopardy, as the case were with a rigid gripper.

For the analysis of the output force a force sensor, as the one shown in Figure 8, will be fabricated. It is also a compliant mechanism and it will enable the measurement of the output force. The sensor will be designed with Solid Works and ANSYS. By applying the forces produced by the gripper's jaws (red arrows in Figure 8), a displacement sensor will monitor the displacement of the force sensor, and this experimental information will be coupled with the known stiffness of the force sensor in order to produce the force value. The class ME 308 Instrumentation and Measurement I take this semester will provide the knowledge I will need to do the measurements that will help to determine the output force and the amplification of the displacement.

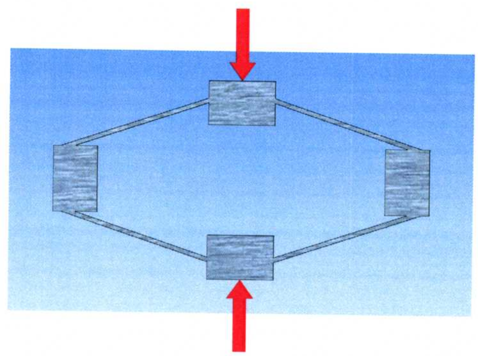

Figure 8. Compliant force sensor

## Anticipated Results

The main benefit for me will be to get more accustomed with analyzing compliant mechanisms by using the specific modeling techniques, such as finite element analysis or analytical ones. The gain of understanding the corresponding design process and experimental testing procedures are other benefits. The following concrete results are anticipated at the completion of this project:

1. A simple model will be formulated enabling the determination of the output force by the gripper for different displacements. This model will assume that the flexure hinges are point-like joints with only torsional stiffness.
2. A more realistic model will be developed for the motion amplification and gripping force to be determined by using real flexure hinges of various configurations (right-circular, or corner-filleted for instance). This model will take into consideration that real flexure hinges have a more complex deformation behavior that includes shear and cross bending for instance.
3. Several compliant mechanisms having various geometries and flexure hinges will be studied in order to achieve a constant force for a wide range of displacements as well as a large displacement amplification. Drawings will be produced with Solid Works or

AutoCad for the selected designs. These designs will be imported to ANSYS and stress and displacement analysis will be performed.

4. A model of a spring will be designed which will be used for the measurement of the force output of the gripper. Both analytical modeling and finite element simulation will be utilized to design a force sensor within a specified force range. The sensor will be fabricated and subsequently calibrated by using a precision non-contact displacement sensor available in the UAA School of Engineering labs.
5. The fabricated gripper device will be experimentally tested by measuring the output/input motions, and the output force. This will be done with the aid of the designed and fabricated force sensor in conjunction with other sensors and actuators available in the UAA School of Engineering labs.
6. Experimental testing will also be performed by using electro-mechanical linear actuators (voice-coils), as well as piezoelectric actuators, and the resulting output/input motions and output forces will be measured again.
7. The sets of results (theoretical – with analytical modeling and the ANSYS software, and experimental – from the analysis with the force sensor) will be used for comparison purposes. Conclusions of possible differences between the two sets of data will be formulated.
8. The project will finish with a written report which will include description of the methods used as well as the relevant findings, results, conclusions and suggestions for further studies concerning the topic of the project.

## Project Budget

The project budget will cover the costs of fabricating the compliant gripper and compliant force sensor together as well as the costs necessary to purchasing actuation and sensing equipment that will supplement the existing equipment in the labs of the UAA School of Engineering. The following section is an approximate breakdown of costs:

*Equipment*

1. Linear displacement sensors and conditioning electronics – approximately $ 2,500
2. Voice-coil linear actuators (various sizes), total cost - $ 400.00
3. Piezoelectric actuators with strain gages - $ 400.00

*Fabrication, materials and shipping* - $ 700.00

Total - $ 4,000.00

## Budget Justification

The costs mentioned in the Project Budget section are only approximate figures, as the prices might vary in terms of the specific conditions at the time of purchasing and manufacturing, but they should be conservative upper-margin estimates.

Since UAA has no fabrication facility to produce compliant mechanisms, this process has to be done by a company which has the required technology. The costs of material and shipping (there is no company that can do Wire EDM in Alaska) have to be paid in addition to the fabrication costs. The sensors and actuators mentioned in the budget section are necessary to enable the operation and operation monitoring of the compliant gripper and compliant force sensor.

## Project References


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## Project Timeline

March-April 2008 – Background research
May 2008 – Development of theoretical models
July-August 2008 – Mechanism design and analysis with Ansys
January-February 2009 – Fabrication
March-April 2009 - Experimental testing
Mid April, 2009 – Presentation at the Undergraduate Research Symposium
May 31, 2009 – Expenditure deadline
June15, 2009 – Final written report deadline