# Comparison of Concentrated and Distributed Compliant Elements in a 3D Printed Gripper*

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**Abstract.** Compliant elements overcome many of the shortfalls of using 3D printing to create mechanisms, as print artefacts such as 'stair stepping' can cause issues with conventional joints. One of the key decisions when designing a compliant mechanism is choosing to either concentrate the compliance into a small region that resembles a conventional hinge, or distribute it over a larger area. This research details the simulated deformation and stress difference between these two types of compliant elements for a 3D printed gripper. Results show that for the same gripper deformation, the distributed compliant element experiences much less stress, at the expense of stiffness in secondary loading directions.

**Keywords:** 3D Printing · Compliant Mechanism · Gripper

## 1 Introduction

One of the benefits to 3D printing grippers, is the ability to produce complex geometries which would be difficult to create using conventional manufacturing methods. The majority of 3D printing processes create parts which are built up of many individual layers, which causes an effect known as stair-stepping on surfaces which are not parallel or perpendicular to the print bed (Figure 1). This effect can cause problems with parts which need to interface with each other like revolute joints, which can require calibration to perform well when 3D printed [2]. Printing curved surfaces parallel to the print bed can reduce stair stepping, but this is not always possible for every joint on a part. Although work has been done to improve the performance of 3D printed conventional joints [4][7], issues such as excess material/support removal still remain. Compliant mechanisms overcome these issues by consolidating multiple parts into a single element featuring some form of compliance. This not only reduces the number of parts, but can also reduce or remove backlash, noise and frictional losses as well as the need for maintenance or lubrication [5][6]. Blanes *et al.*[1] showed a single

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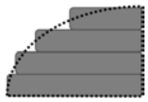


**Fig. 1.** Stair Stepping

(a) Concentrated (b) Distributed

**Fig. 2.** Comparison of Concentrated and Distributed Compliant Elements

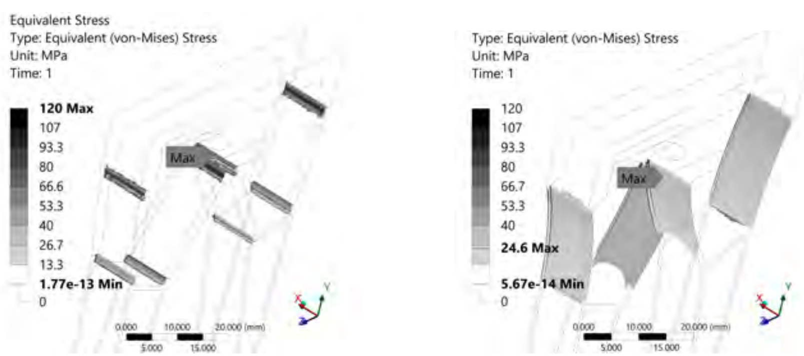
piece gripping mechanism featuring two coils to allow rotation of the digits, using an external pneumatic cylinder for actuation. This shows that a simple one-piece 3D printed gripper can be created to transfer a linear input motion to an opposed gripping motion. Compliant mechanisms can be classified into two sub-divisions. The first and most common type is concentrated or lumped compliance [3], which is where a mostly rigid part has small regions where elastic deformation is concentrated as a hinge. The second type is where the compliant region is spread over a much larger area, distributing the stress concentration and compliance [8]. Figure 2 shows two elements, one with concentrated compliance (2a), and one with distributed compliance (2b).

## 2 Compliant Gripper Simulation

Figure 3 shows the deformation of two grippers. The first features rigid elements with compliant regions concentrated as hinges. The second is the same gripper but with sections which distribute the compliance. The same 5N load is applied to the tab of each gripper in the -Y direction (shown by black arrow). It can be seen that the 5N load results in approximately the same deformation of the input tab and tips for both mechanism designs. Analysing the stress in the compliant regions showed a maximum (von-Mises) stress of 120MPa for the concentrated compliance element, and 24.6MPa for the distributed element. A significant difference, considering how similar the overall deformation is. As the tensile strength of many common 3D printing materials such as PLA, PETG, and Nylon is around 50MPa, this would cause the concentrated compliant regions to plastically deform or break completely. Figure 4 shows von-Mises stress regions over 10 MPa for both grippers. One observed benefit to the concentrated compliance design is that as the compliant region is much smaller, the stiffness of the element to deflections in other axes is much higher. Figure 5 shows a simulated comparison between deformation of the concentrated and distributed compliance gripper mechanisms after a 5N load is applied to the side of the same tab (in the x axis, i.e., not the direction intended for operation). It can be seen that the distributed compliance regions allow much more deflection in this axis than the concentrated compliance regions. The colour scales have been matched to make visual comparison easier. The simulations assume isotropic material properties, as the gripper can be 3D printed using a process which produces isotropic mechanical properties (such as MJF), or using an FFF process with the gripper oriented such that the deformation will act in the plane of the layers, which will act in an essentially isotropic manor.


(a) Concentrated Compliance (b) Distributed Compliance

**Fig. 3.** Deformation of Concentrated and Distributed Compliance Gripper

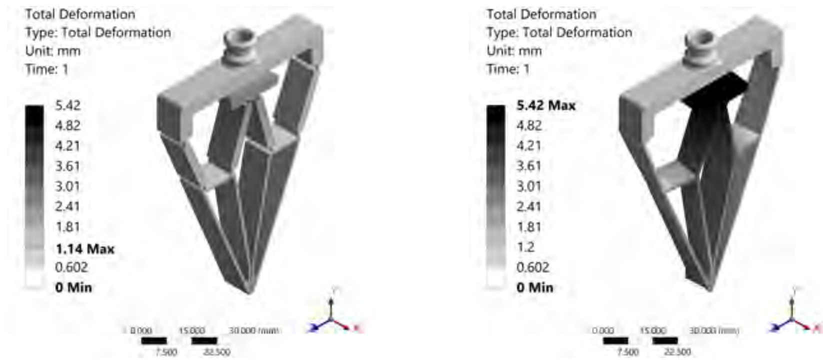



(a) Concentrated Compliance (b) Distributed Compliance

**Fig. 4.** Concentrated vs Distributed Compliance Equivalent Stress Capped IsoSurface

## 3 3D Printed Grippers

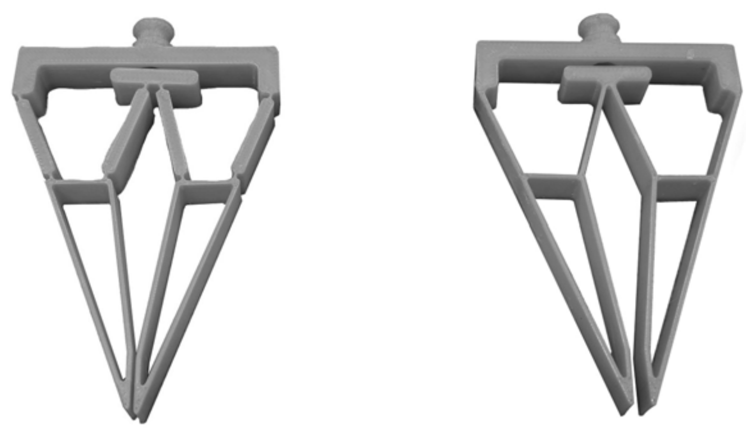
Both gripper designs were 3D printed using the Fused Filament Fabrication (FFF) process (Figure 6). Experimental testing showed that the 3D printed compliant grippers act in the same manner as the simulated grippers, with a similar amount of deflection in the intended direction, but much less stiffness




(a) Concentrated Compliance (b) Distributed Compliance

**Fig. 5.** Comparison of off-axis deformation

in other axes on the gripper with distributed compliance. As expected from the much higher simulated stress on the concentrated compliance gripper, plastic deformation occurs, resulting in the gripper not returning to the original position. Without limiting the deformation to prevent this, the lifespan of the gripper would likely be much lower than the one with distributed compliance.



(a) Concentrated Compliance (b) Distributed Compliance

**Fig. 6.** Prototype FFF 3D printed grippers

## 4 Conclusion

Although the concentrated compliance mechanism shows less off-axis deformation, the much higher stress causes it to plastically deform, altering the performance and likely reducing its future reliability. Distributing the compliance across a larger region reduces the stress concentration and allows the gripper to deform elastically without damage, but this does also make the gripper more susceptible to deformation in other axes. Careful consideration should therefore be taken when developing one-shot 3D printed mechanisms to ensure that the type of compliance is suitable for the desired deformation. Future simulation or experimental work into the performance of the grippers whilst interacting with objects could show additional advantages or disadvantages between the two designs. Hybrid approaches which use a combination of concentrated and distributed compliance could also be explored, tailored based on the results found in this work.

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