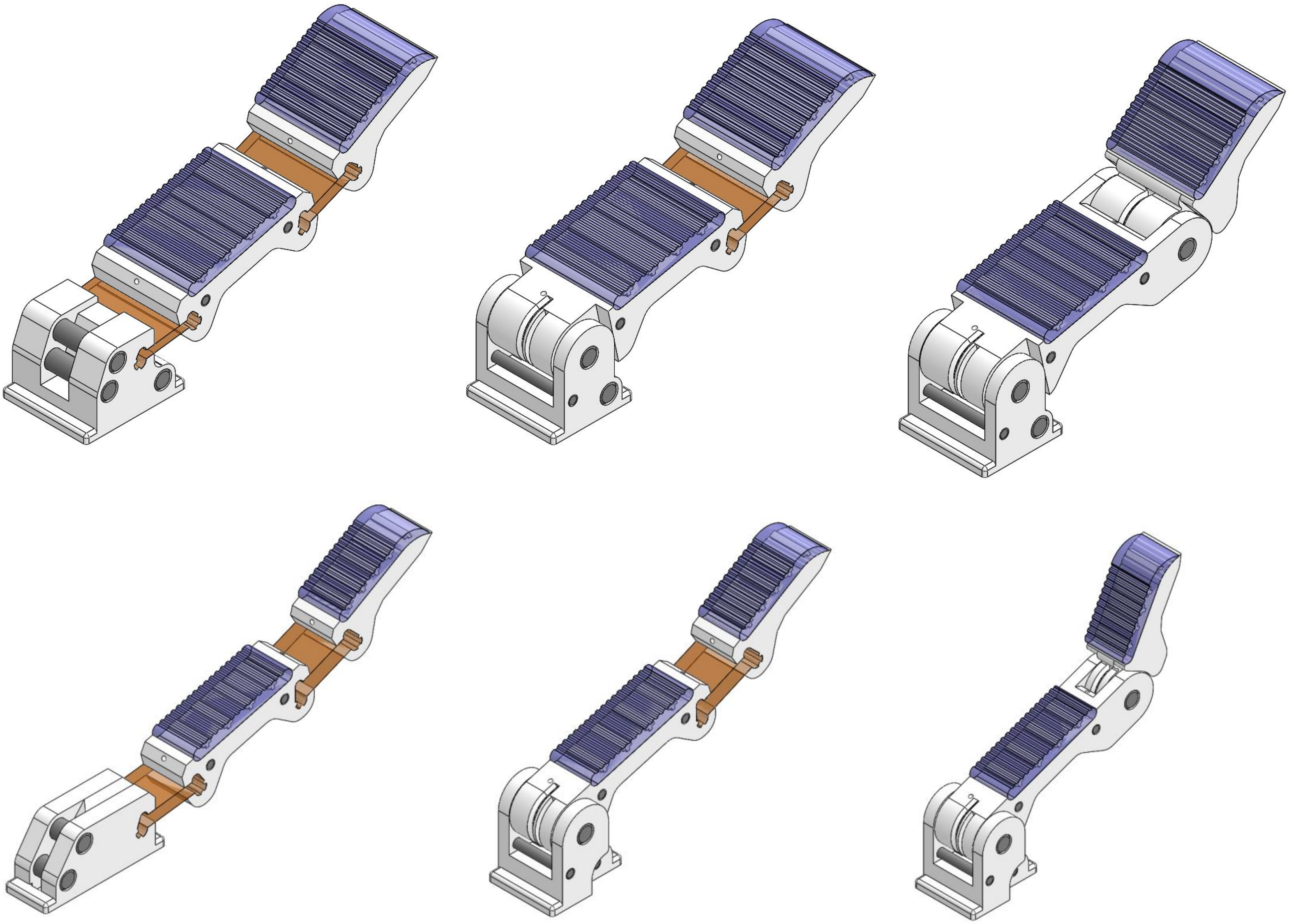
OpenHand

Finger Guide

Version 1.0



Flexure-Flexure   Pivot-Flexure   Pivot-Pivot

Fabrication Instructions

Last updated: February 20, 2015

Overview

The finger designs in the Yale OpenHand Project and the way in which they're fabricated are the key innovative features of our hands. I provide several finger options for each hand design, but they are essentially identical in terms of the fabrication and post-processing steps needed for each. To preserve what remains of my sanity, and so I don't have to repeat some variation of the instructions for each unique hand's documentation, this is a generalized guide to making the OpenHand fingers. Please read through this guide thoroughly to ensure that the fingers will function as they are intended.

Godspeed,
Raymond Ma

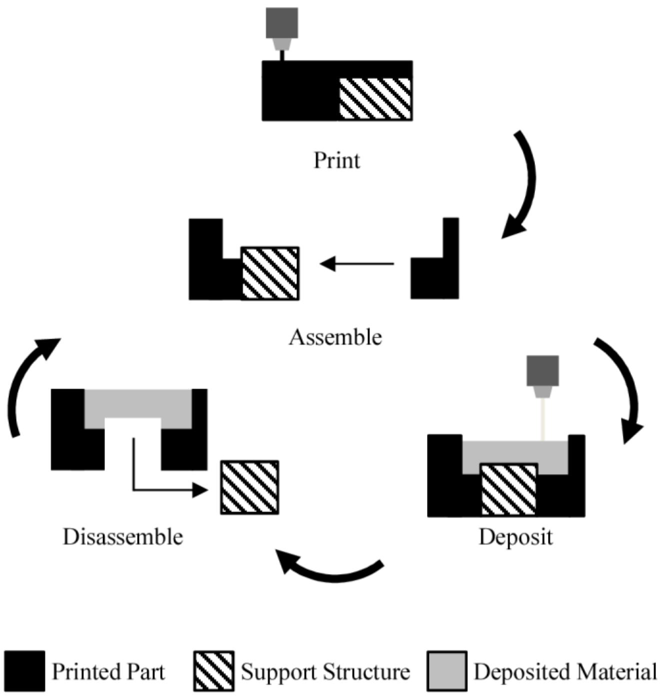
Types of Fingers – The Yale OpenHand Project supports up to three types of fingers, designated by their proximal and distal joint types:

- **Flexure-Flexure** – flexures at both the proximal and distal joints. Very compliant and robust due to its monolithic design, but susceptible to twist-out behavior when used for precision-grasping tasks. Joint stiffness is determined by the geometry of the joint flexures.
- **Pivot-Pivot** – traditional revolute joints with pins at both proximal and distal. Joint stiffness is determined by additional elastic elements, such as springs (extension or torsion) or elastic bands
- **Pivot-Flexure** – traditional pin joint at proximal, flexure joint at distal. This still provides a high degree of compliance and robustness due to the use of a flexure, but it is also appropriate for precision manipulation tasks, as the proximal pin joint avoids twist-out behavior.

Finger Actuation – All fingers are tendon driven. We do not support any linkage-driven actuation schemes. The use of tendons allowed us to make the hands more modular, so that entire sets of fingers could be interchanged on top of the same actuation base. It also makes the overall design more compact. We suggest 100lb test Power Pro Spectra, as that is the brand we use, though any non-stretch tendon with diameter less than 0.7mm should work fine. For those of you unfamiliar with tendon-driven mechanisms, the biggest challenge will likely be tying off tendons with secure, no-slip knots. My personal preference is the improved clinch knot, but feel free to experiment.

Return Springs – Tendons are single-acting, meaning they can only pull, not push, so joint stiffness is necessary. For pin joints, this return action is implemented through springs. The library provides the option to use either torsion springs or extension springs. I like torsion springs for their compactness and consistency, but there is a very limited selection given our size requirements. There is a more varied selection for extension springs, but they would require you to anchor them through tendons instead of purely mechanical features on the fingers, so that may be inconsistent depending on the assembly.

HDM



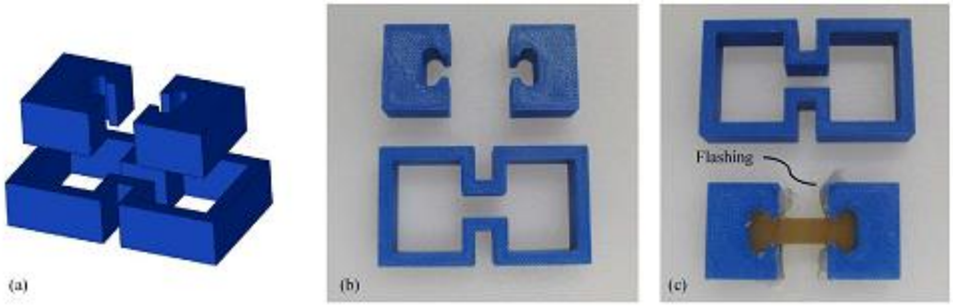
Hybrid Deposition Manufacturing (HDM)

1. Print mold components
2. Assemble mold
3. Deposit urethanes/resins
4. Disassemble mold

For each finger, we provide by molds that use thin, sacrificial walls as well as multi-part molds that can be disassembled by hand. In terms of efficiency, I would suggest the thin-wall molds, but some beta users had requested multi-part molds to simplify some of the post-processing and pre-deposition steps.

Example w/ Thin wall Molds [Video]
Example w/ Multi-part Molds [Video]

Thin-wall molds



Multi-part molds

HDM – Preparing Molds

Molds need to be sealed properly prior to resin deposition. The easiest way we've found to do this is metal foil tape, commonly used for HVAC. This tape has good adhesion and durability but can also be easily removed after the resins cure. We've also had success with painter's scotch tape in the past, though adhesion has been an issue.

Depending on the viscosity of the urethanes you use, leakage is to be expected, so it's in your best interest to properly seal the bottom of the molds as much as possible. The multi-part molds use a snap-together frame to minimize leaking.

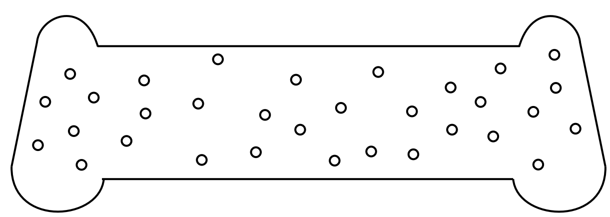
Multi-part molds

Thin-wall molds

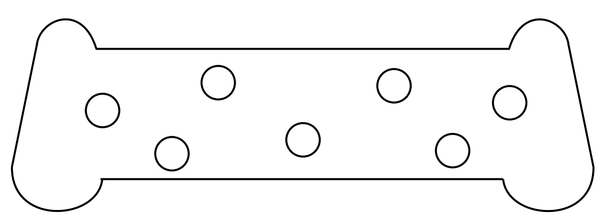
HDM - Urethanes

We recommend a precision balance scale, with resolution of at least 0.1g for accurate measurement and mixing of urethanes. The Yale OpenHand Project generally uses two-part urethanes: PMC-780 for flexure joints, and Vytaflex 30 for pads. We advise that you add the urethane parts to the same container. Do not measure the urethanes separately and then pour both into a common mixing container. The high viscosity of these urethanes can result in an error in that case.

As recommended by the manufacturer, the urethanes should be degassed in a vacuum chamber after mixing, whenever possible. Degassing should take only a few minutes. You should see a large rise followed by a sudden drop in material level. If you are at a university, degassing chambers should be available through your art department or any group that works with cast molds.



Degas



No Degassing

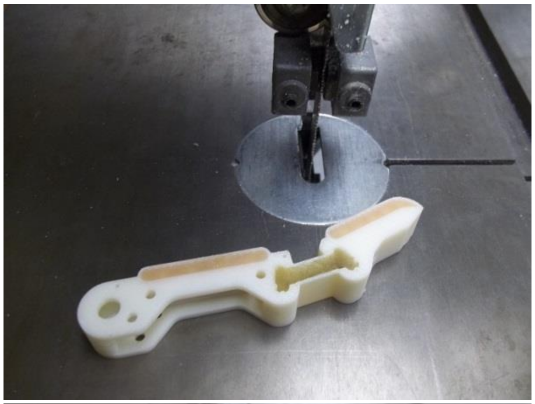
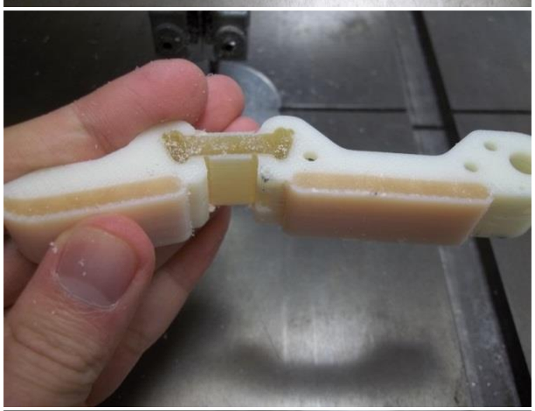
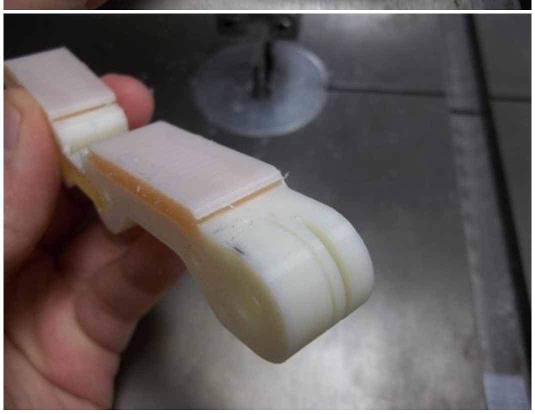
HDM – Pouring Urethanes

Pour resins slowly and with as thin of a stream as possible. This mitigates bubble formation. Do not pour haphazardly and so quickly such that you trap bubbles under the poured urethane. If this is your first time pouring urethanes, you will probably make a mess.

You'll want to pour more than necessary, such that convex meniscus forms. Your urethanes will probably leak out of the mold before it fully cures. Excess urethane material can be easily cut away during post-processing. Be wary of the pot life and working time of your urethanes to ensure that you're not pouring the urethanes too slowly.

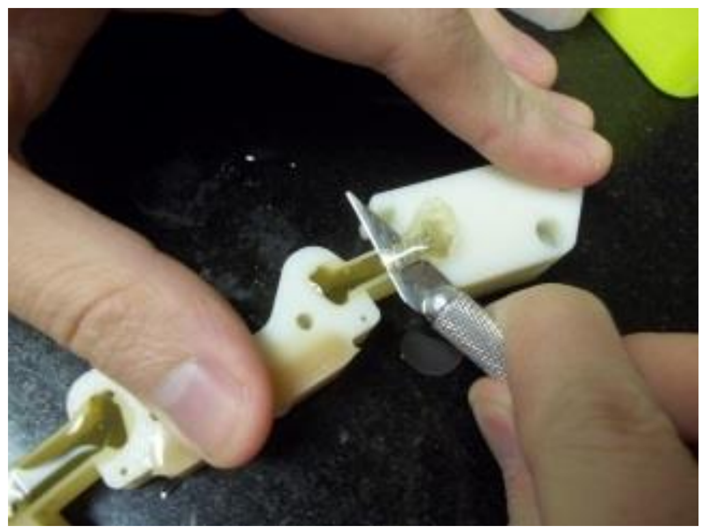
After pouring, it's likely that there will be visible bubbles either on the surface or just below the surface. You can take a needle, another tool with a sharp point, or a can of compressed air to burst them.

HDM – Wall Removal


Excess cured urethanes can be removed with a sharp blade. We prefer scalpel blades or razor blades versus serrated blades. The urethane is soft and compliant, so a sander or a file may not work very well.

For thin-walled molds, the sacrificial walls are most easily removed on a bandsaw. You don't have to cut all the way through the wall. With just a partial cut, you can snap the walls apart with a flat-head screw driver or just by flexing the joints for cast flexures. Excess ABS or jagged cuts can be cleaned with a blade or small file.

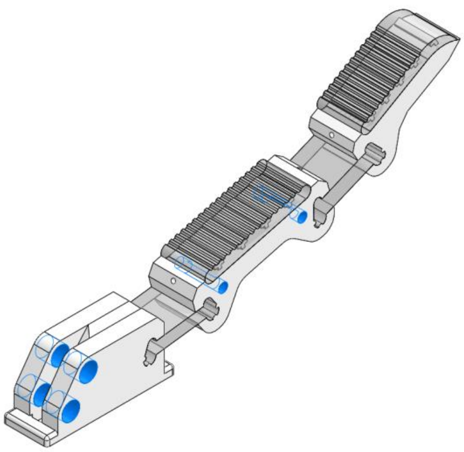
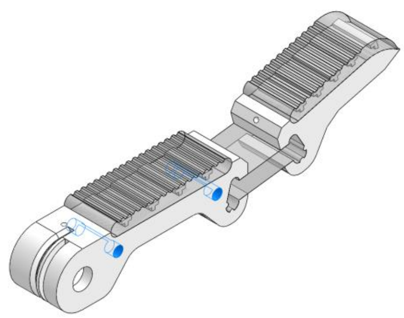
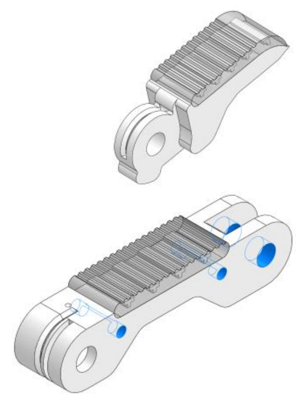
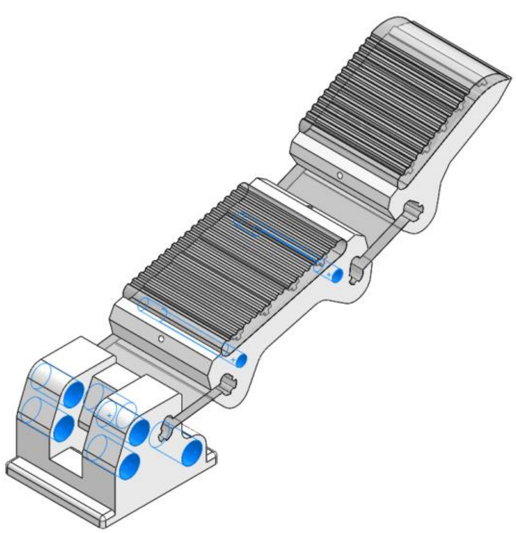
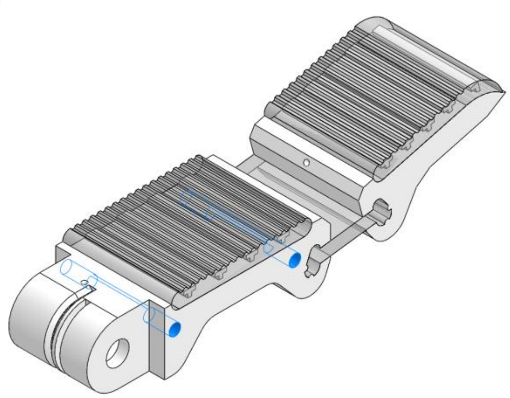
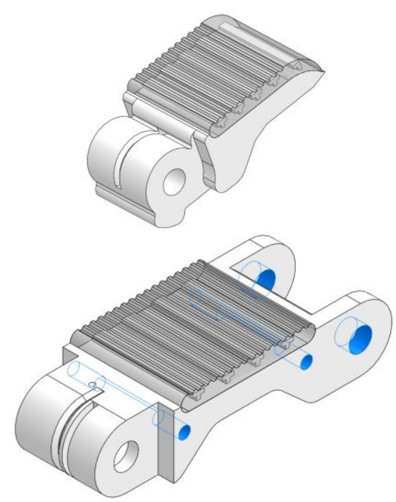


Post-Processing

reaming press-fit clearances

Tools
0.1240” reamer [2791a51]
0.2490” reamer [2791a53]
hand drill (or drill press)

Press-fit clearances for tendon rerouting pins and the female pair of pin joints should be cleaned with an undersized reaming bit. The clearances in the CAD are sized such that reaming is unnecessary assuming the part is printed perfectly, but it is recommended that you use a reamer just to be safe.

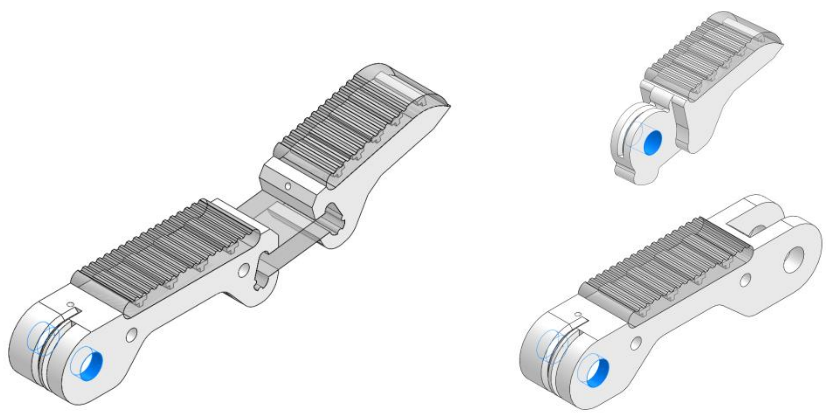
Post-Processing

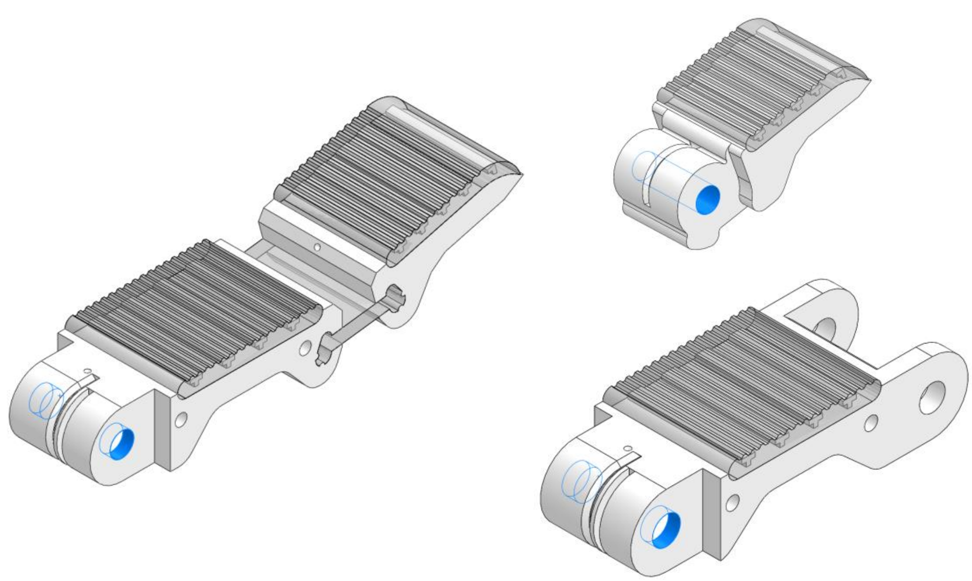
REAMING JOINT CLEARANCES

Tools
0.2510” reamer [2791a33] - or - 17/64” drill bit
hand drill (or drill press)

Joint clearances should be cleaned out with an oversized reamer. Like with the press-fit clearances, the CAD files should have these clearances sized appropriately, but the reamer will be useful in fixing any inconsistencies in the print.

You shouldn’t need to do this for the flexure-flexure style fingers





Post-Processing

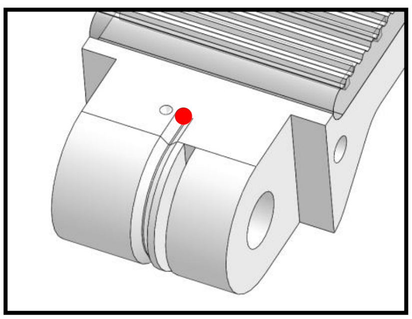
drilling tendon ports 1/2

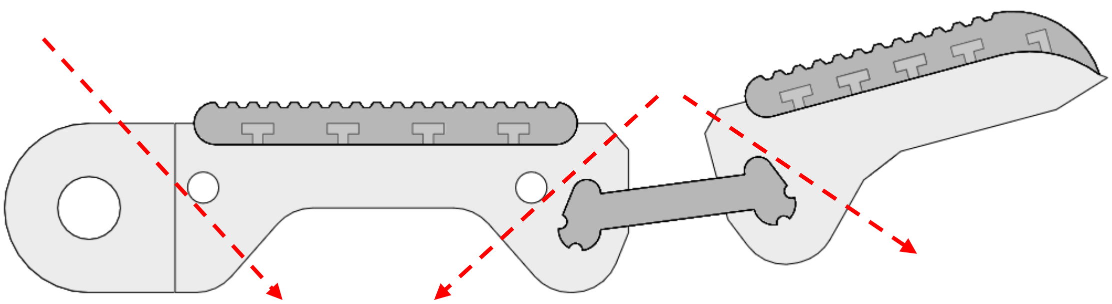
Tools
Drill bit Ø less than 1.5mm (1/16”)
drill press
vice

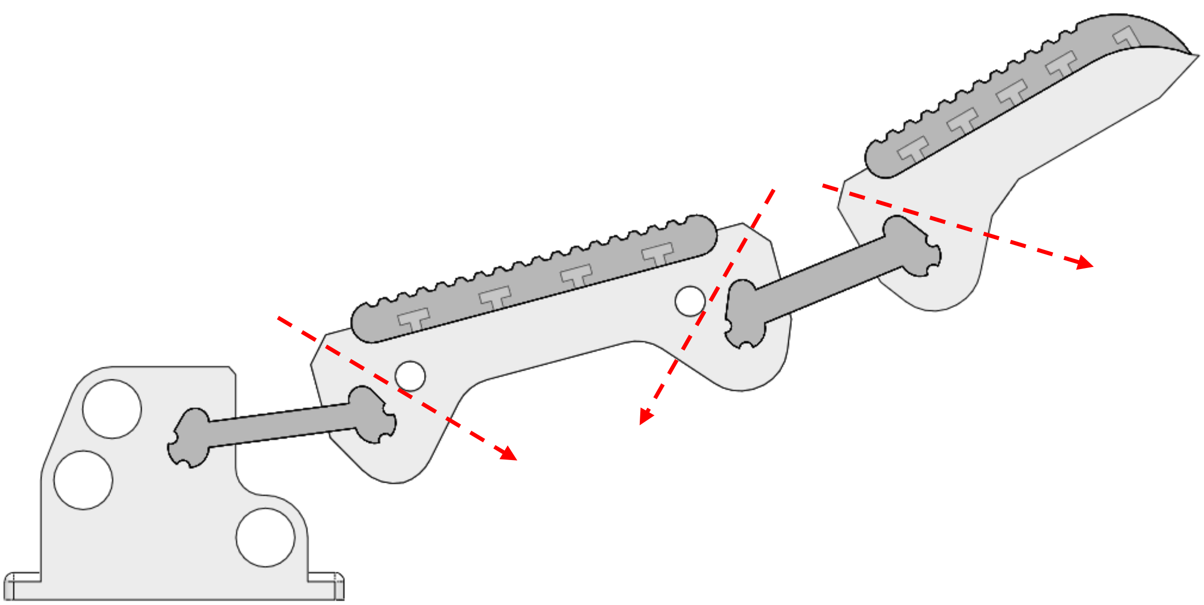
There are starter divots for the tendon ports along the centerline of the fingers. These ports need to be drilled such that the tendon will run freely and tangentially to the steel routing pins. The finger designs have a surface on the side opposite the tendon port that will be perpendicular to the desired tendon routing direction.

For the pivot-pivot and pivot-flexure finger designs that accommodate a torsion spring, be careful that you’re drilling the port in the center of the finger and not accidentally drilling the clearance for the torsion spring.

It is not critical how the tendon port on the distal link is drilled, as the tendon merely terminates here.

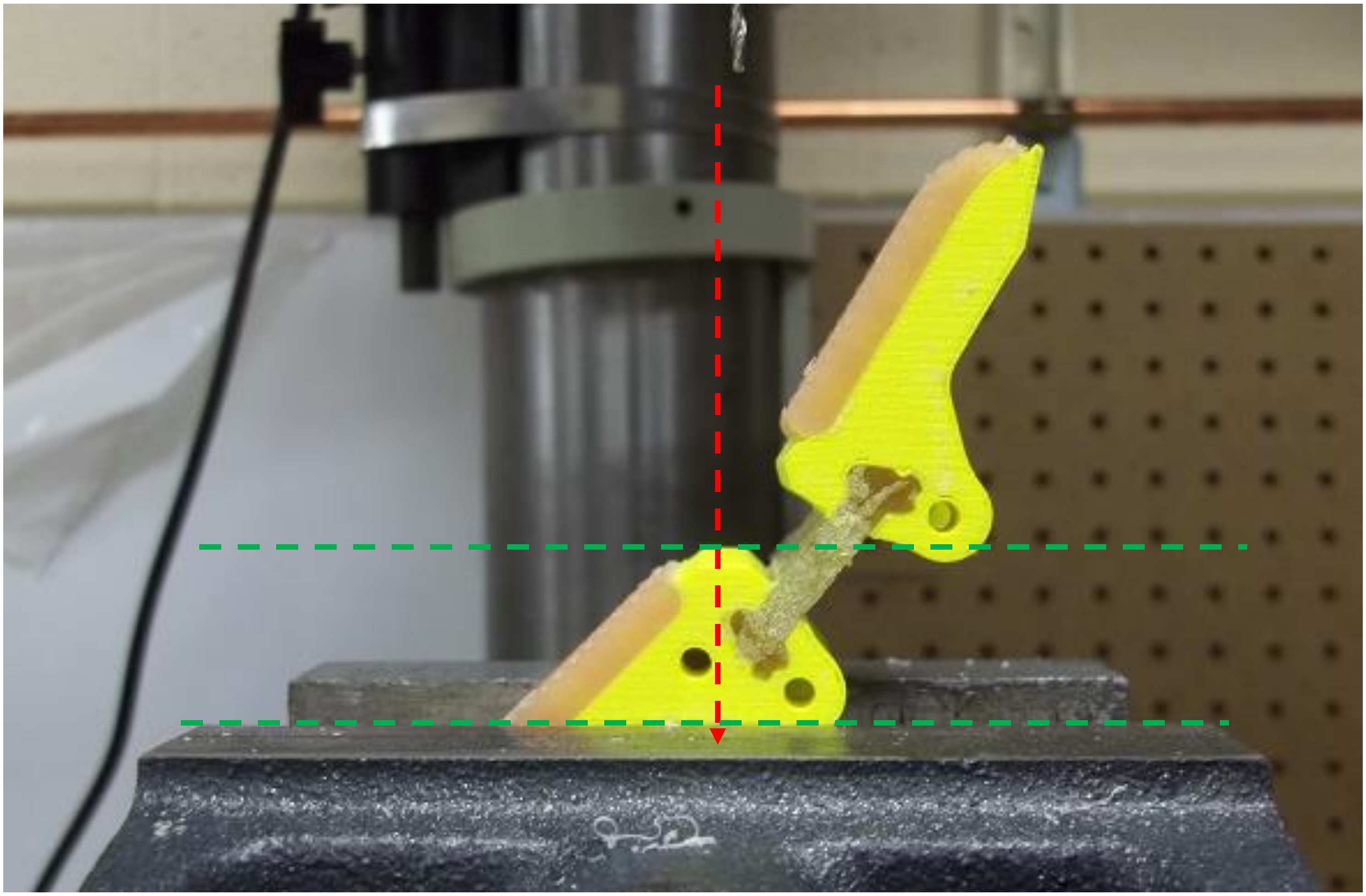


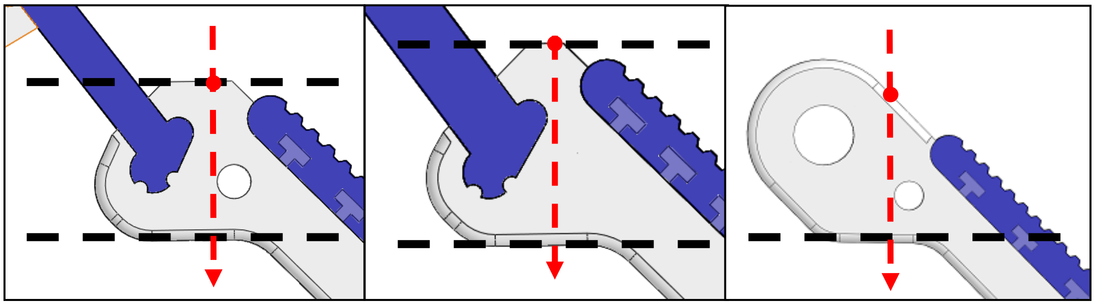


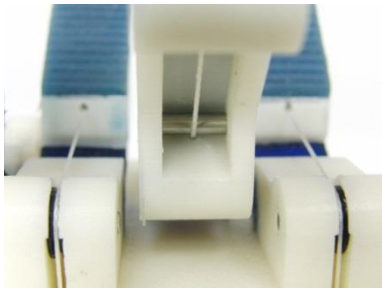


Post-Processing

drilling tendon ports 2/2





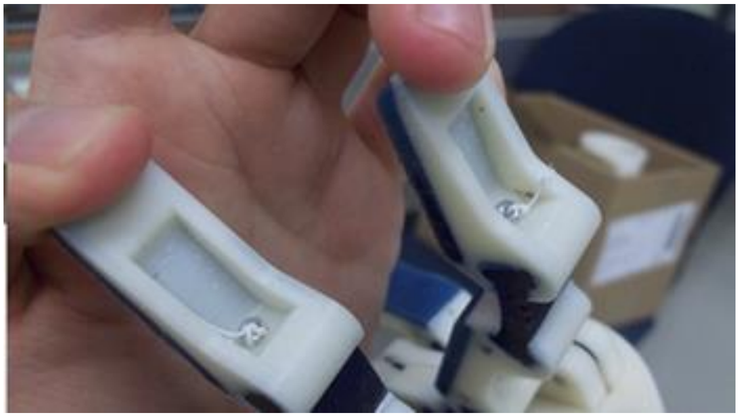


The tendons need to slide freely through these tendon ports and across the steel re-routing pin. If not, your best option will be to use a drill bit with a bigger diameter and re-drill the hole. I have also had success re-drilling the tendon port with a hand drill, but angling the bit when I'm drilling such that I only generate more clearance on one side of the pre-existing hole.

Your best option is to do it right the first time. Measure twice, cut (or drill) once.

Post-Processing

TENDON TERMINATION

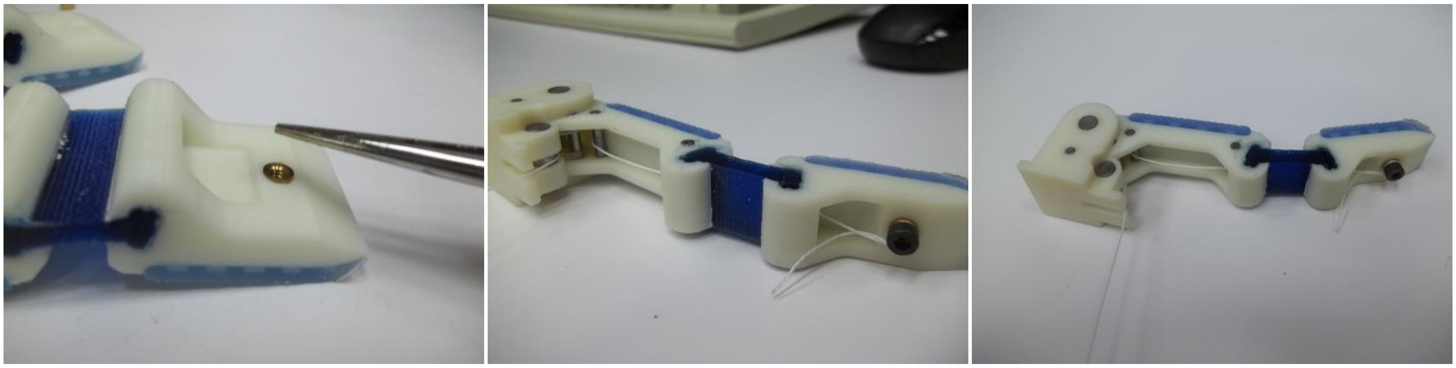


- Using a nut to terminate the tendon

The tendon is terminated at the distal end of the fingers. This can be done two different ways:

1. Tie tendon to a nut or washer
2. Use a press-fit or heat-set insert in combination with a bolt and tie off the tendon to this bolt

We've recently moved to using heat-set inserts and bolts as the tendon termination point, because it's a cleaner and more professional-looking solution, but using a nut would functionally work just as well.



- Using a threaded insert and a bolt to terminate the tendon

Tying off the tendon at an exact length can be difficult, especially if you'd like a no-slip knot. Ideally, you don't want the tendon to be slack during the operation of the hand. My current approach is to take advantage of the capstan effect and wrap the tendon around the bolt or through the nut a couple of times prior to tying it off. I usually use a simple knot with a couple of half-hitches followed by more wraps around the bolt or nut. This isn't a no-slip knot, but I typically do not have termination failures this way while still having some control over my final tendon length.

Keep in mind that the fingers are underactuated, and you can force the tendon to go slack during assembly. It may be helpful to mark the desired tendon length with a marker and then bend the joints such that you have more room to tie the tendons.

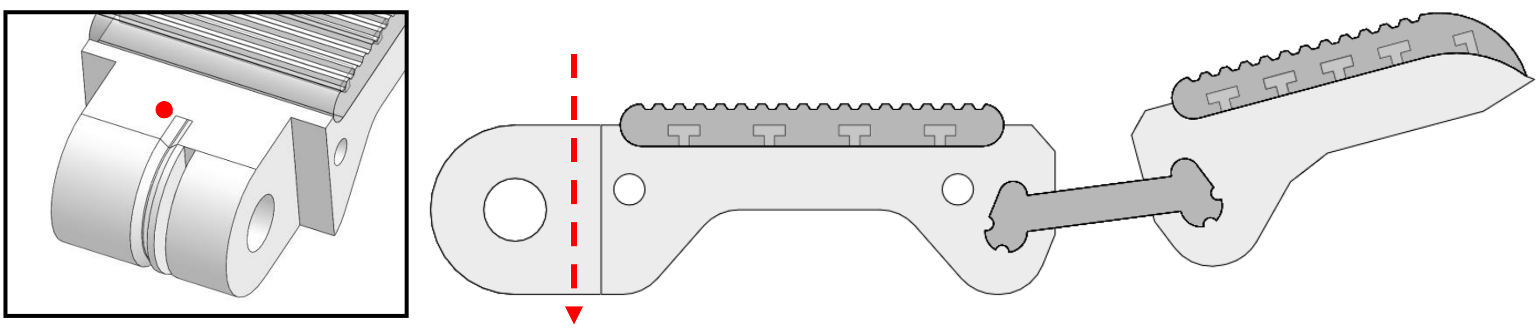
Post-Processing

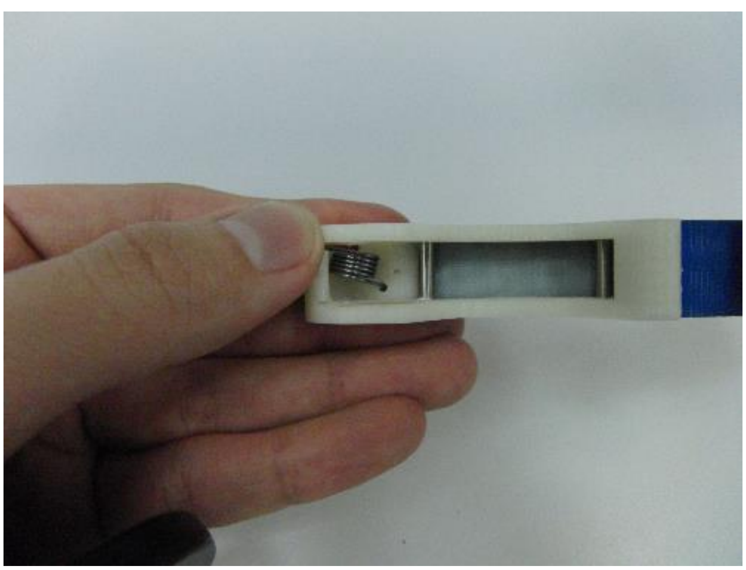
TORSION SPRING INSTALLATION

Tools
Drill bit Ø 1/16” (or similar size)
Dremel w/ cut-off wheel
Hand drill (or drill press)

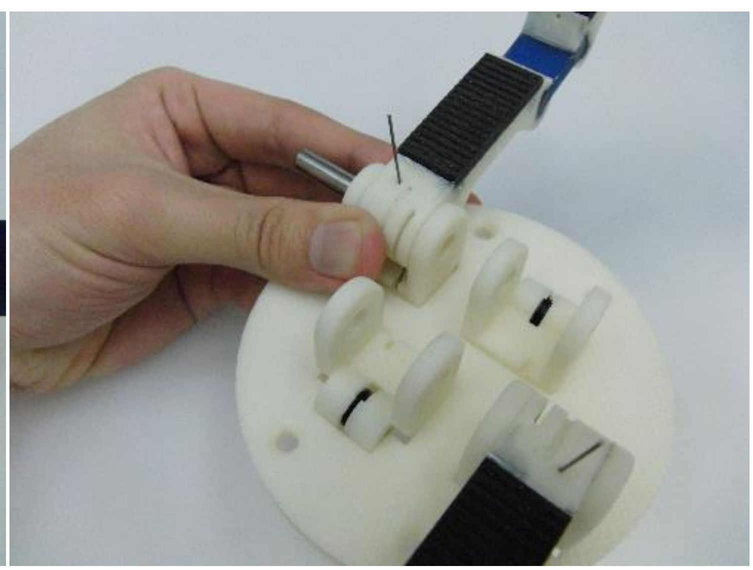
For fingers with a pivot base (proximal pin joint) and a torsion spring allowance, the torsion spring will go around the joint pin and fit into the base slot of the proximal link as shown below.

The installation should be in one of the final steps of the hand assembly, when the finger is installed on its base. The base component (usually named *c1*), should have a pin or some surface right underneath the finger where one stem of the torsion spring will rest. The torsion spring stems should be cut off with a dremel. You will likely damage wire-cutters if they are used.





1. Insert torsion spring stems into slot and offset hole clearance



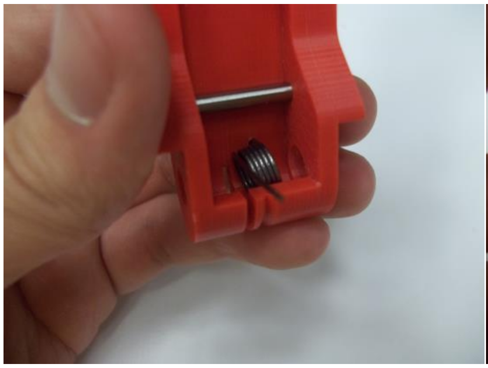
2. Position finger appropriately and press in the joint pin in the final assembly step

Post-Processing

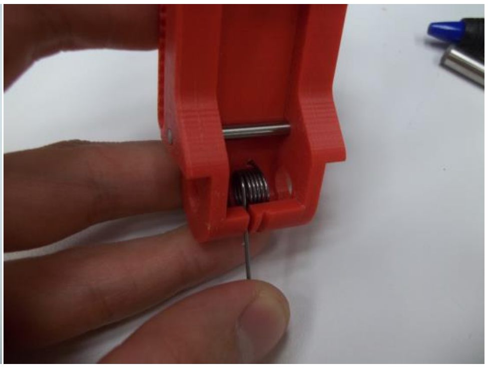
TORSION SPRING INSTALLATION

Another view of torsion spring installation. This should be identical for all base pivot joints that use torsion springs in place of the extension spring.

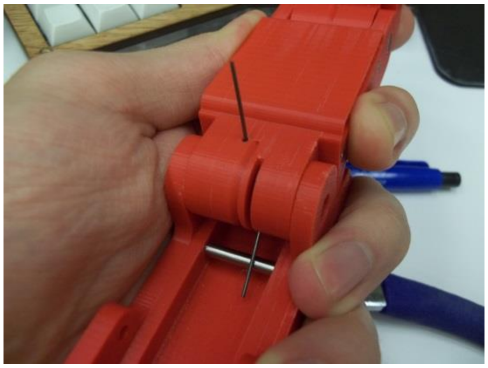
1. Drill hole for torsion spring stem. A divot for this should be incorporated into the CAD



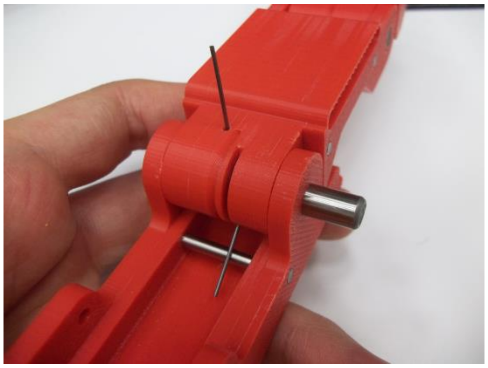
2. Insert one stem of the torsion spring into the drilled hole



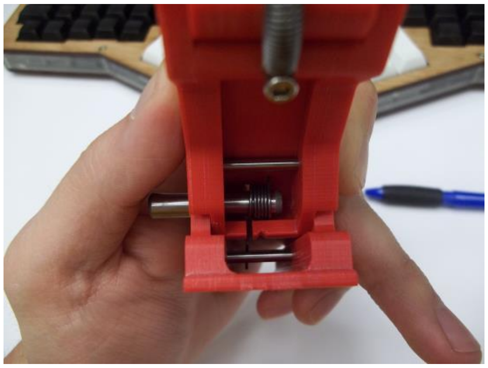
3. Align other torsion spring stem in the slot. You may need to temporarily hold this in place



4. Hold the finger base in position. The base should have some feature (a pin in this case) for the torsion spring stem to rest upon.



5. Press-fit the joint pin into the base joint to complete the assembly



6. Check that the joint pin properly goes through the torsion spring during this assembly step

Post-Processing

EXTENSION SPRING INSTALLATION

Extension springs just need termination points on the two separate bodies connected by the joint. At the proximal joint, due to the length of the proximal link, you will need an additional length of tendon to tie the extension spring to the finger base (part *c1*). Usually, I anchor the extension spring right next to the distal joint to a 2-56 bolt and tie the tendon between the other loop of the extension spring and a pin in the finger base. This pin in the finger base is the same pin that the torsion spring would otherwise rest on.

At the distal joint, this is most easily done with a pair of pins, either in combination with threaded inserts or just threaded directly into the finger link's plastic body.

Extension springs can also be replaced by some combination of orthodontic bands, but I've found that they tend to degrade pretty quickly over time. Orthodontic bands may be a useful alternative when experimenting to find the optimal joint stiffness.