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Purpose:

The purpose of this document is to guide users on constructing a Bowden-transmission system for OpenExo, with the goal of providing a base from which researchers can innovate on end-effector design. This guide, and its associated designs, centered on interfacing with AK-series motors, of which three different sizes can be used (AK60V1.1, AK70, and AK80). For simplicity, this guide will cover the construction using the AK60V1.1 motor, but the process is identical for the other sizes as well (with small variations in components used to account for difference in sizing and the torque generation capacity between motors). Future work will include designs for even more of these motors as well as motors from other companies (i.e., Maxon).

Fabrication of Parts:

Most of the components for this Bowden-transmission system are 3D printed. In addition to these, there are two machined components, the sprocket and the cable-chain interfaces, which will need to be manufactured in-house or by a 3rd party. This section aims to provide an outline for the fabrication of these parts.

3D Printed Components

If you do not have a 3D printer, it is possible to have a company, such as Protolabs Network, print these components for you. While we use, and recommend, Onyx material for our prints, you are more than welcome to use alternative materials. Below is a list of the 3D printed components to this system, the design files for each of these can be found in the "Parts" folder associated with this document.

- Cartridge
- Belt-to-Motor
- Back Cover
- Strain Relief Shell
- Motor Cable Strain Relief

It should be noted that some of the sizing and spacing of these components vary depending on the motor (i.e., AK60V1.1 vs. AK80). It is important to print the proper size of the components for the desired motor. The files are organized such that all parts corresponding to a given motor size (e.g., AK80) are within a folder corresponding to the name of that motor. It should also be noted that there is one additional 3D printed component for the AK70 motor called "Cartridge Spacer". This is included as the shape of

the AK70 motor is slightly different compared to the other motors, which would prohibit the same general design scheme used for the other motors.

In addition to these components, there is one final 3D printed component to the system called “Strain Relief Inserts”. We print these using thermoplastic polyurethane (TPU), but feel free to use a material with similar quality if you so desire. These components are designed to reduce the strain applied to the steel-cable/Bowden-tube exit point from the 3D printed material as this was an area with a higher failure rate compared to the rest of the system.

Machined Components

Moving on to the machined components, these consist of the sprocket and the cable-chain interface. If you have the capability, you may machine these components yourself. Otherwise, a third-party such as Xometry can machine them for you. Note that there are differences in sizing for both the cable-chain interfaces and the motor sprockets depending on choice of motor (to account for differences in Motor design and the torque generating capability of the motors). Similarly to the 3D printed components, the proper sizes of these can be found in the respective motor size’s folder under the name “Cable_chain_interface_MOTORSIZE.SLDPRT” and “Sprocket_MOTORSIZE.SLDPRT.” We use 6061 T-6 aluminum for the cable – chain interface and 15-5 stainless steel for the sprocket.

The Chains

Similar to the other components, the chains are sized based on the motors used. If you’re using the AK60V1.1 motor, you’ll need the smaller chain size which can be ordered here (6mm pitch, 4mm roller diameter, and 2.8mm roller width). If ordering from McMaster Carr, the minimum length you can order is 1’ of chain. You’ll need two chains of about 6” in length, so you’ll need to size the chain yourself once you have it. You’ll also need a total of four master links, which can be ordered from the same page.

If you’re using the AK70 or AK80, you’ll need a larger chain, which can be ordered here (8mm pitch, roller diameter of 5mm, and 3 mm roller width). You’ll need two chains 7” in length but again, the minimum length you can order from McMaster Carr is 1’ so you’ll need to order 2’ and size accordingly yourself. As with the AK60V1.1, you’ll need a total of four master links as well, which again can be ordered from the same page as linked above. **Make sure that you order the correct size for your chain**.

The sections below will assume you have the correct size and length of chain on hand.

Construction:

The following sections will serve as a guide for the assembly of the device. It will be assumed that you have already printed and machined the components mentioned above. It may be beneficial to review all of the following sections before beginning assembly so that you know the general path before embarking. As mentioned previously, some components are sized differently depending on the motors used and thus may appear different from the parts that you have. The sizing used in the following sections is for the AK60V1.1.

Preparing the Cartridge and Backplate

Beginning with the cartridge in which the chain and cable sit, grab the 3D printed cartridge and press the bearing into its designated slot in its center.

Next, grab the 3D printed backplate and press an M3 threaded insert into the hole in the bottom of the part as seen below. Later, a screw will pass through this insert to fasten everything together.

Preparing the Motor and Sprocket

Now we will fasten the sprocket onto the motor. The sprocket will interface with the chain, which in turn interfaces with the cables that actuate the exoskeleton.

Grab the motor and sprocket as well as six M3x8 screws. Use the screws to secure the sprocket onto the face of the motor. The screws will pass through holes on the sprocket and will thread into the six threaded innermost holes on the motor (two of the holes are not threaded). Some of these holes may be a bit more challenging to secure as some of the sprockets teeth partially overlap with them, but with some careful effort (you may have to back out other screws to get it to sit properly) it should be possible to fasten them. **Be careful not to overtighten these screws during this step as it is easy to punch into the center of the motor damaging it!**

Making the Chain-Cable Assembly

As mentioned previously, the chain and cable chain interface sizes will depend on motor size. As such, the components below may appear slightly different than the ones you have. Once you have the properly sized chain, remove the master links. To do so, grab a pair of pliers and use them to remove the fastener that holds the master link in place. Once the fastener is off, also remove the master link. An image with the fastener and master link removed from the chain is shown below. Make sure to do this for both sides of the chain.

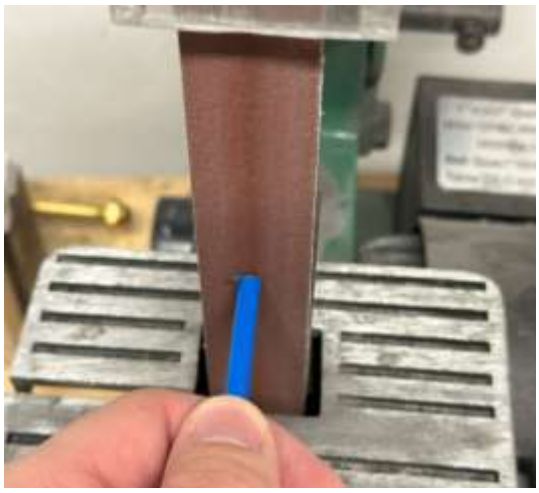
Once the master links are off, place the cable-chain interfaces onto the now open links on both sides of the chain. Replace the master links and their fastener over the interfaces to secure them (a pair of pliers or tweezers will be helpful during this step). With that, the chain is ready to accept the cables. Again, both sides of the chain need an interface.

Next, cut cables (two for each motor, four total bilaterally) to the desired size for the user of the device. You will need to determine this length for yourself. Once cut, thread the cable through the bottom of the chain-cable interface and crimp. The process is shown below.

Once the end of the cable is crimped, slide the cable back through the interface so that the crimp sits inside the slot of the interface as seen below.

Repeat this with another cable on the other side of the chain.

Next, we'll cut bowden-tubes to the needed length for the cable. Measure how long you need the tubes to be and cut using a dremel. The ends of the cable may be damaged from the cut. If so, use a belt sander (or if one is not avialbe, standard sand paper) to smooth the ends.



Further, you'll likely need to clear out some of the interior sheathing of the bowden tube, so that the steel calbe can properly slide into the tubes. To do so, take a small hex key (or any small tool) and use it to clear out some of the interior sheathing near the end of the tube so that the cable can run freely through it. If the cable runs freely into the tube, on both ends, then it should be ready for assembly.

Putting the Motor Assembly Together

Take the chain and cable assembly and thread the cables through the bottom two holes of the 3D printed cartridge and place the chain around the bearing in the top portion of the cartridge, as shown in the images below.

Place the motor onto the cartridge such that the shaft of the sprocket goes through the hole in the bearing and the chain can interface with the teeth of the sprocket. Once the motor is on, ensure that the chain is properly engaged with the sprocket by pulling on one end of the cable. You should feel the resistance of the motor as you pull. Make sure that the cable-chain interfaces are evenly aligned (relativly) within the cartridge. If they are not this can cause issues during operation where the interface runs into sprocket, potnetially damaging both and leading to device failure.

Once the chain is properly engaged, use four M3x10 screws to fasten the cartridge onto the motor. *Ensure that the cable ports on the motor are facing upward (red arrow).*

Thread an M3X6 screw with a washer into the threaded hole in the middle of the bearing.

Slide the Bowden tubes onto the cables and flip the motor over and set the backplate into place. Do not screw it in yet. We will first put the strain reliefs into place.

Slide the TPU strain reliefs over the Bowden tubes.

Slide the strain relief shell over the TPU strain reliefs and pull the TPU strain reliefs all the way to the bottom of the shell.

Slide the strain relief shell over the cartridge so that the holes align.

Flip the motor over and use an M3x30 screw to fasten the strain relief shell to the cartridge.

Preparing the Hip Belt

Using the 3D printed mount and a sharpie, mark the position of four mounting holes on either side of the belt with the Belt to Motor 3D printed piece used as reference. Try to have this aligned as straight as possible or slightly angled as that the Bowden tubes exiting the cartridge point out away from the body.

Use a 5mm bit to drill the four mounting holes whose positions you just marked

Press four M5x20 screws through the holes on either side such that the threaded ends stick out the back side of the belt.

Mounting the Motors onto the Belt

With the belt now ready to accept the motors, screw the 3D printed mounts onto the motors as shown

Mount the motors onto the belt using the screws you set into the belt and M5 lock nuts

And with that, the assembly of this belt-side Bowden-transmission system is finished. We leave the end-effector side design and assembly up to you to innovate and utilize as you see fit!