**Pin-Insert Design**

**Diagram of a diagram of a structure

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**Concept:**

Design contains a permanent magnet located vertically above an air-core coil. Attached to the magnet is a pin that routes flux lines through the air-core of the coil, across its windings, and into magnetic shielding around the coil (see COMSOL image for flux path). The reaction force generated in the pin/magnet assembly is strongest when the pin is at the bottom of the stroke and decays approximately linearly with stroke position. In this design, kinetic energy is generated in the pin over the stroke (~4 mm) before contacting the user. This design yields impulses with similar energy (~10% more) compared to the Hapti-Comm device, with a footprint that is ¼ smaller in cross-sectional area (5 mm diameter compared to 10 mm).

The key advantage of this design is that by aligning the permanent magnet and coil vertically, magnets and coils with larger diameters can be used in comparison to a concentrically aligned approach. Energy output could be further improved in this device by using pin and shielding materials with higher permeability and saturation points. Scaling the coil and pin height would also improve force output, although these effects are more modest.

One limitation of the design is that the flux generated across the coil is limited by the saturation of the pin. Increasing the height of the magnet has little effect on force. A further limitation of this design is that the largest forces occur at the bottom of the stroke and decay by a factor of 10 at the top of the stroke. Thus, generating oscillatory signals at a biased position (as done in the Hapti-comm) would be less effective in this setting. Another potential limitation is Eddy currents in the pin and shielding, which are yet to be analyzed fully.

One consideration for any impulse-based device is the return stroke. Normally, this is accomplished by applying bipolar signals to the actuator. With our current electronic system, we are only able to provide uni-polar signals. Modifications to the electronic circuit will likely be needed to accommodate an impulse-based design.

**Components:**

1. PTFE Guide: guides the actuator along a single axis. The component height was selected to be 3/8” (~9.5 mm) such that the piston contacts the finger after 4 mm of travel along the stroke. We can adjust this contact point easily for experimentation by shimming the PTFE guide. PTFE is easy to machine on the benchtop CNC in lab (have already fabricated a few prototypes without issue). For an array of actuators, a single plate with holes can be used. Only negative is that PTFE is kind of expensive ($70 for a 6” x 6” x 3/8” sheet).
2. Contacting Piston: contacts the finger, acts as a linear guide with the PTFE, and provides a mechanical stop for the actuator. The height was selected to be 1/2” (~12.7 mm) to satisfy the length-diameter ratio (L/D > 2) recommended for linear guides for all piston positions along the stroke. The diameter was selected to be 2 mm, yielding a small contact area with the finger (lower finger stiffness, more displacement). This component can be machined from any ½” metal sheet that doesn’t have strong magnetic properties (current idea is aluminum). Must fabricate and attach one of these components for each actuated element.
3. Shielding: acts to minimize electromagnetic cross-talk between actuated elements and helps route flux lines across the coil. The shielding has an inner diameter of 4.5 mm, yielding a thickness between adjacent actuators of 1 mm (more analysis needed to confirm if this will sufficient, but flux lines look reasonable in COMSOL). The component height is 5/8” (~15.8 mm), surrounding the coil and magnet along its entire stroke. The height selection specifies the location of the mechanical stop to be at 7 mm along the stroke (3 mm displacement into the finger). The component will be made from 1018 low-carbon steel, which has very similar magnetic properties to soft iron. 1018 low-carbon steel has less corrosion issues, less eddy current issues, is cheaper to source, and easier to machine than soft iron. This material is commonly machined on CNCs, although it will be too hard for our benchtop CNC. For an array of actuators, a single plate with holes can be used.
4. Magnets: Produces magnetic fields across the coil, yielding reaction forces that drive the actuator. The magnet has a 2-mm height, which was determined by sweeping heights in COMSOL and determining that increasing the height above 2 mm has almost no effect on force production (due to saturation of pin). The magnet has a diameter of 3 mm, to maximize its diameter without generating large interaction forces with the shielding and/or other magnets (needs further analysis to see feasibility of 4 mm). This dimension is a stock dimension at Super Magnet Man for N50 neodymium magnets.
5. Pin: Used to route magnetic flux lines across coil. The diameter of this component was determined to be optimal at 1.5 mm using a sweep (looking at trade-off between coil and pin area). The pin height was selected to be the same as the coil height 6 mm. Increasing the height of the pin relative to the coil is helpful but would require a through-hole in the PCB. Increasing both pin and coil height does improve force output, but it is a diminishing effect due to pin saturation. Similar to the magnetic shielding, it will be fabricated from 1018 low-carbon steel (similar reasons for material selection). The pins (6 mm + . 35 mm flange) can be fabricated from a stock 1/4” plate. Must fabricate and attach one of these components for each actuated element.
6. Coil: Used to convert electrical inputs to reaction forces on the permanent magnet. The coil 6 mm tall and has an ID of 2 mm. These geometric choices were made in conjunction with the pin, as described above. The coil has an OD of 4.25 mm, leaving a small gap (.25 mm) to insert into the magnetic shielding. The coil has ~400 turns, is ~ 7.7 ohms, and consumes 0.4 A (1.2 W). We will be custom sourced from venders in China (some of these parameters might have to be adjusted based on vendor capabilities).
7. Ferrite Base for Core: Acts as an SMD mounting surface on the bottom of the coil and as an attractor for the magnet/pin assembly. This attractor ensures that the magnet/pin assembly is stable at its base position. This will help with the return stroke and for crosstalk or other perturbations (similar approach was also used in the Hapti-comm). This attractor/latching force has little effect on the driven response of the system and decays rapidly with distance along the stroke (pretty much to zero at 1 mm).
8. PCB: Converts light signals into electrical signals for the coils. Currently I am just using the circuit design from electrotactile project. Need to modify.

**Performance:**

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| Performance Metrics | Our Design | Hapti-Comm |
| Energy delivered to finger (mJ) | 0.26 | 0.24 |
| Actuator diameter (mm) | 5 | 10 |
| Actuator Height (mm) | 27 | 28 |
| Stroke Length (mm) | 4 | 4 |
| Moving Mass (g) | 0.3 | 3 |
| Velocity at Contact (m/s) | 1.3 | 0.4 |
| Stroke Time (ms) | 6 | 20 |
| Full-Cycle Frequency (Hz) | 83 | 25 |
| Force during Biased Operation (mN) | 30 | 60 |
| Power Output (mW) | 22 | 12 |
| Power Input (mW) | 1200 | 1400 |