

E-Scroll: A Rotational Haptic Ring Using Electrostatic Adhesion

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Abstract—Wearable haptic devices offer opportunities for subtle, always-available tactile feedback, yet many existing designs rely primarily on vibrotactile actuation, limiting the range of sensations that can be conveyed. This work presents a rotational haptic ring that applies electrostatic adhesion to modulate contact forces during rotation, enabling directional tactile feedback in a compact, ring-worn form factor. By controlling adhesion during rotation, the device can generate variable tactile sensations without relying on large actuators or external surfaces. This work-in-progress explores electrostatic adhesion as a mechanism for rotational haptic feedback, highlighting its potential for compact, low-profile wearable haptics.

I. INTRODUCTION

Compact wearable haptic devices are limited by size, power, and mechanical complexity [1]. As a result, they often rely on vibrotactile actuation. While effective for alerts, vibrotactile feedback provides limited support for conveying spatially grounded, intuitive haptic information. Ring-worn devices are well suited for rotational interaction, making them compelling for directional haptic feedback. Prior work has explored rotational interaction in ring-based haptic devices using passive mechanical actuation mechanisms [2]. Whereas prior electrostatic-based interfaces have been limited to planar surface interactions [3], this work is the first to apply electrostatic adhesion to modulate rotational resistance in a wearable ring form factor.

II. WORKING MECHANISM

Electrostatic adhesion is generated by applying a high-voltage potential across electrodes separated by a dielectric layer. In the proposed ring, this effect is used to modulate rotational motion between a stationary inner ring and a concentric outer ring with narrow clearance, as shown in Fig. 1. In the unpowered state, friction between the rings is low, allowing the outer ring to rotate freely under small applied forces. When a voltage is applied across the electrodes, Maxwell stress generates electrostatic adhesion between the two rings, increasing friction and restricting motion.

A commercial copper-dielectric laminate (3M, part number C0619E-FULL-35U-12X18) was used as the dielectric layer. One copper layer was removed prior to assembly, leaving a single-sided copper-dielectric structure. The dielectric membrane consists of a ceramic-filled epoxy composite with a nominal thickness of $t = 19 \mu\text{m}$ and a manufacturer-specified capacitance density of $(C/A) = 9.61 \text{ pF/mm}^2$.

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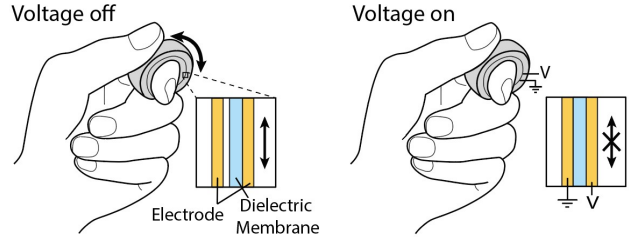


Fig. 1. Locking mechanism for a rotational haptic ring based on electrostatic adhesion.

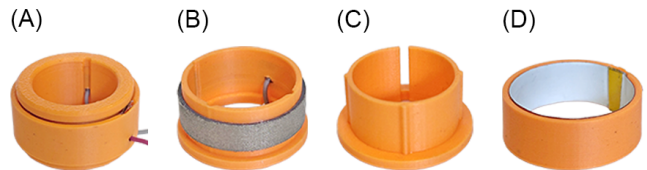


Fig. 2. Ring prototype components: (A) fully assembled device; (B) inner ring assembly with inner electrode stack; (C) inner retaining ring that constrains the assembly; and (D) outer rotating spinner ring with copper-dielectric stack.

Based on these specifications, the effective relative permittivity is estimated to be on the order of $\epsilon_r \sim 21$ under a parallel-plate approximation.

Conductive nylon tape with silver threading was chosen as the counter-electrode across the dielectric layer to achieve low sliding friction.

III. PROTOTYPE DESIGN

The device consists of an inner ring assembly and an outer rotating ring, as shown in Fig. 2. The inner ring assembly remains stationary relative to the finger and is composed of two rigid components that interlock to form a closed ring. The ring was 3D printed using PLA on a Bambu Lab X1 Carbon printer.

The outer ring incorporates a single-sided copper-dielectric stack on its inward-facing surface (total thickness = $114 \mu\text{m}$), bonded to the ring structure using a thin acrylic adhesive (3M 467MP), as shown in Fig. 3.

The inner ring's outward-facing surface consists of conductive nylon tape, backed by a corona-treated silicone elastomer to provide tolerance [4], and bonded to the rigid structure using the same acrylic adhesive (total thickness = $710 \mu\text{m}$), as shown in Fig. 3. Each electrode is connected via a wired electrical lead that is routed through a recessed channel in the ring structure to minimize rotational interference.

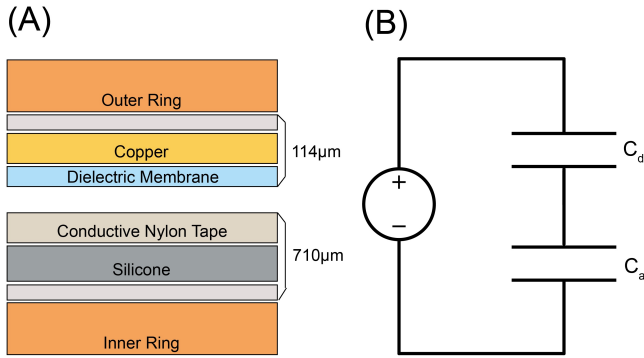


Fig. 3. Layered electrode stack of the rotational haptic ring: (A) physical layer stack; (B) equivalent series-capacitance circuit model.

The layered electrode stack is modeled as two capacitive elements in series, as shown in Fig. 3, where C_d corresponds to the dielectric membrane and C_a represents the interfacial air gap between the dielectric membrane and the conductive nylon tape. The series configuration assumes uniform contact across the electrode overlap area, such that the dielectric and air gap capacitances stack in series at each point of contact.

The ring is compact and lightweight (< 4 g), with an overall height of 11 mm, an outer diameter of 16.5 mm, and a thickness of 8.4 mm. The total surface area of the electrode overlap region was calculated to be approximately 934 mm^2 . Under an idealized parallel-plate approximation, the electrode stack yields an estimated upper bound on the order of 9 nF.

IV. PRELIMINARY RESULTS

The effective capacitance of the electrode stack was approximately 60 pF. Compared to the idealized parallel-plate estimate of approximately 9 nF, this result suggests that the electrical behavior of the interface is strongly dominated by the interfacial air gap. Using the measured electrode overlap area, this value corresponds to an equivalent air gap distance of $140 \text{ }\mu\text{m}$.

This gap is attributed to surface roughness, limited conformal contact between the inner and outer rings, and nonuniform contact during rotation, which limits the electrostatic adhesion force in the current prototype.

Under the current driving conditions (1 kHz square wave at $500 \text{ mV}_{\text{pp}}$ with 1–30 Hz amplitude modulation), electrostatic adhesion produced perceptible vibration-like sensations primarily at higher modulation frequencies (20–30 Hz), with minimal response at lower frequencies.

V. APPLICATIONS

While pinch and tap gestures are effective for selection, rotational interaction enables users to perceive continuous or directional changes through touch. As illustrated in Fig. 4, the rotational haptic ring supports both gesture-based thumb input and knob-like rotation. One application is as a virtual scroll wheel or dial for extended reality (XR), where modulated rotational resistance can convey discrete steps similar to the notched behavior of a mouse scroll.

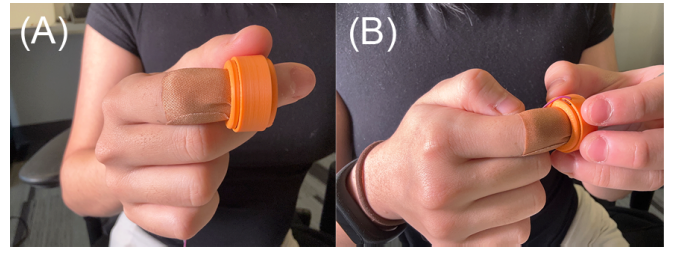


Fig. 4. Example interaction modes with E-scroll: (A) Gesture-based input using thumb motion. (B) Knob-like rotation, where the ring functions as a tactile dial.

VI. CONCLUSIONS AND NEXT STEPS

This work presents a prototype of a compact, lightweight rotational haptic ring that leverages electrostatic adhesion to provide always-available, directional haptic feedback. Preliminary results demonstrate the feasibility of achieving directional haptic feedback in a ring-worn form factor without motors or bulky mechanical components.

Future work will focus on reducing the interfacial air gap by improving conformal contact between the inner and outer rings. In parallel, a differential driving scheme will be explored to remove the need for a wire on the rotating outer ring by placing both active leads on the stationary inner ring.

To quantitatively characterize rotational resistance, future work will measure the torque required to rotate the outer ring as a function of applied voltage using a motorized testbed. A subsequent perceptual study could assess whether users can detect and discriminate haptic feedback during rotation.

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