

HIGH DENSITY ELECTROMAGNETIC ACTUATORS ON PRINTED CIRCUIT BOARD FOR TACTILE DISPLAYS WITH HIGH SPATIAL RESOLUTION

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A recently presented selective electromagnetic actuation technique allows vibrations of multiple tactile elements to be controlled using a single coil based on the individual mechanical resonance frequencies. This technique allows realization of many tactile elements in a smaller area. We present a new structure by transferring the design to a Multi-layer Printed Circuit Board (PCB) to show a wire wound coil capable of mass production in a scalable technology allowing for an affordable and lightweight portable device whilst miniaturizing the coil to increase the mechanical force generated and the spatial resolution over the same area. The finite element analysis (FEA) on multiphysics model developed for this transducer are in agreement with the optical vibrometry measurement results, which successfully validates the proposed method for transferring the design to Multi-layer PCB.

Index Terms—Electromagnetic Devices, Vibrometer, Magnetic Field, Tactile Elements.

I. INTRODUCTION

Vibrotactile displays offer significant potential for conveying graphical information through the sense of touch. The large size of actuators limits the spatial resolution of these displays, although the tactile acuity of fingertips for perception of graphical information is less developed compared with our visual system, the limited user acceptance of tactile displays is substantially caused by some key technological challenges. However, the manufacturing and assembly process for the electromagnetic coils is labor intensive and not cost effective for a scalable device.

II. BACKGROUND

The spatial resolution constraint is directly related to the physics of actuators. The mechanical force generated by coils in response to supplied electrical current is limited by the coil dimensions, which can tolerate a certain amount of electrical power [1-3]. Furthermore, wire wound coils utilized in a tactile display require manual assembly onto a PCB, as the displays become larger, the manufacturing and assembly process grows exponentially[4]. Figure 1 shows the preceding design with a 4x4 taxel array actuated by one electromagnetic coil for each suspended taxel and cantilever beam [5]. The innovative electromagnetic transducer technique in Figure 2 shows the transition from wire wound coils to Multi-layer PCB. Our simulation results show the optimized design for maximum mechanical force whilst reducing the physical dimensions of the coil.

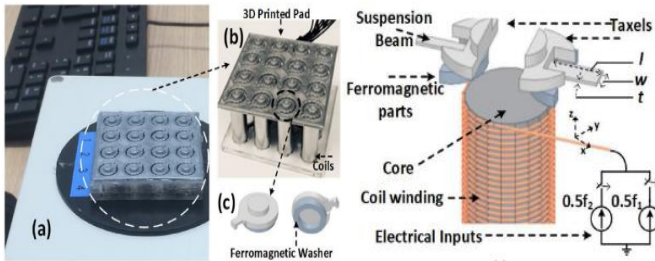


Figure 1 – (left)(a) low resolution vibrotactile display, (b) array of off-the-shelf coils (c) Taxel 3D model, (right) 3D model of two taxels on one coil supplied by two single-tone electrical currents [6].

III. DESCRIPTION OF THE METHOD

We have replicated the off-the-shelf coil design by effectively transferring it to Multi-Layer PCB where 8 turns per layer and 6-layer boards are stacked to create a continuous coil through 60-layers of PCB, whilst previous approaches have been 2-layer PCB limiting the number of turns and coil length [3, 4]. Figure 3 shows a layer from the PCB along with an improved and optimized design for future developments. The FEA on multiphysics model shows the different magnetic flux density generated between the coils (Figures 4 & 5). This shows a reduction in the magnetic field generated but is consistent with the reduction in the number of turns compared to the mass-produced coil. We have further developed an improvement in the coil design, but initial tests were required to prove the concept. Figure 6 shows the optical vibrometry results compared between both technologies to validate the FEA analysis results.

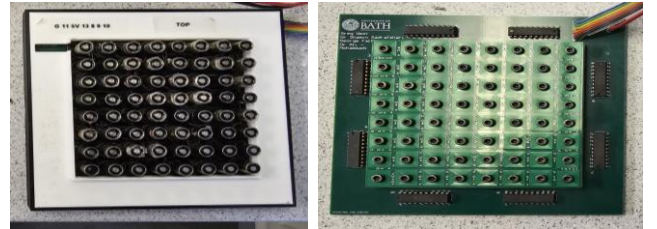


Figure 2: Off-the-shelf wire wound electromagnetic coils (left), Multi-layer PCB (right).

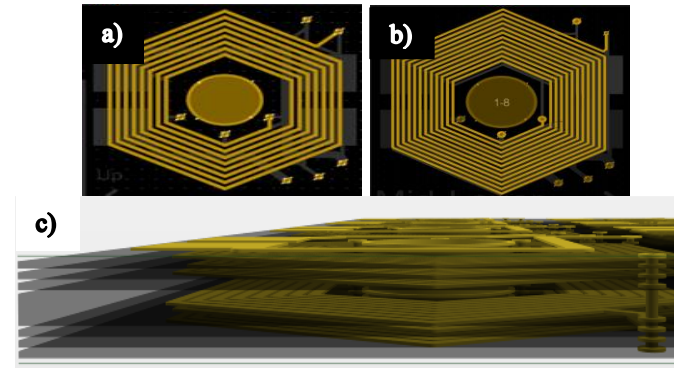


Figure 3: (a) Current design of multi-layer PCB coils, (b) Improved and optimized design, (c) 3D view of PCB planes

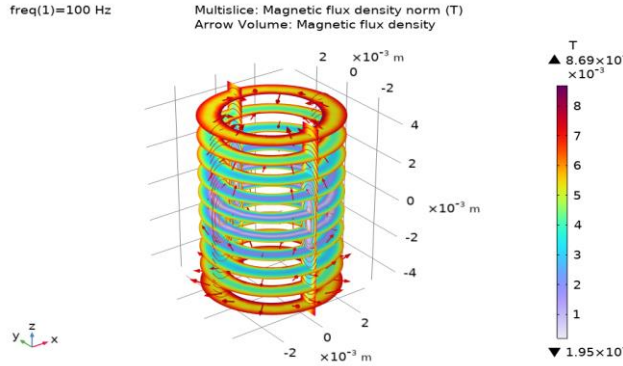


Figure 4: FEA Analysis for the Off-the-shelf electromagnetic coils shown in Figure 2 (left).

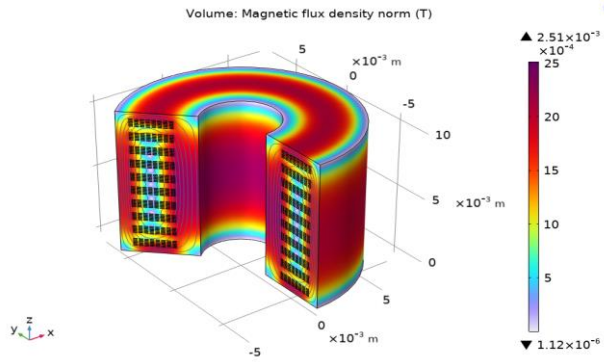


Figure 5: FEA Analysis for the current multilayer PCB design.

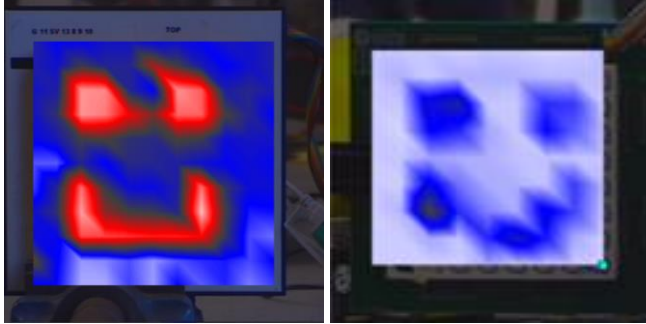


Figure 6: (left) Off-the-shelf electromagnetic coils, (right) Multi-layer PCB, Thermal image showing displacement magnitude of the tactile elements.

IV. EXPERIMENTAL RESULTS

The prototype was tested by measuring the displacement generated by the 3D printed taxel faceplate placed above the coils with the coils controlled by a microcontroller and a Graphical User interface (GUI) as shown in Figure 7. Figure 6 shows the difference in amplitude variations which are in agreement with the FEA results shown in Figures 4 & 5. The displacements magnitude is approximately half on the PCB variant compared to the wire wound coil when a pulse of 80mA is applied. We also show an optimized design where the number of turns has increased whilst the footprint has been reduced and increased the copper layer thickness of the planar coils (Figure 8). The FEA analysis shows an increase in the magnetic flux density within the Multi-layer PCB coils with further work planned to characterize this on a prototype using the PolyTec vibrometer and to align displacement amplitudes closely with an increase in spatial resolution.

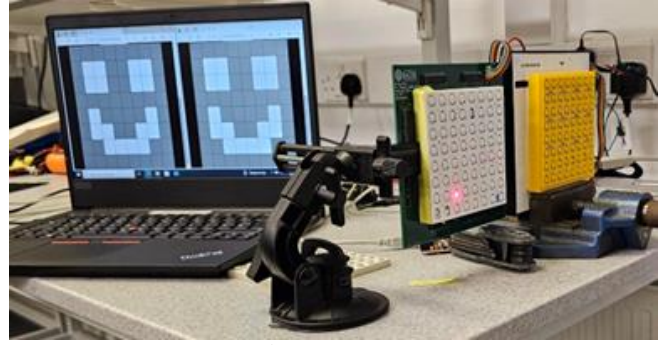


Figure 7: Graphical User interface controlling the respective tactile display shown on the laptop screen.

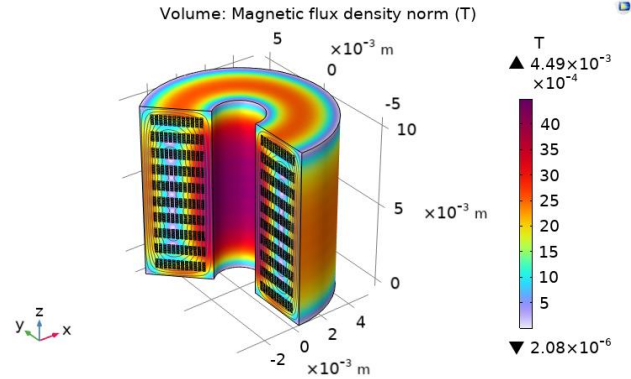


Figure 8: Reduced footprint with an increase turns in planar PCB coil showing an increase in magnetic flux density.

V. CONCLUSION

The results shown in this paper are very promising and show the relevant magnetic field created on a scalable platform which can be increased to bring in line and supersede the mass-produced electromagnetic coil. Our future work will aim at increasing the magnetic field generated by the optimization of the multilayer PCB and analyze the thermal effects related to the power dissipated within the prototype coils.

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