the z-direction. For example, piezo-electric actuators, voice coil actuators, or moving magnet actuators can be directly coupled to the touchpad or touchscreen to provide direct motion of the touch surface. Piezo-electric actuators are described with reference to copending patent application Ser. No. 09/487,737. Also, the touchpad surface can be comprised of a fixed tactile surface and a reference surface, where the reference surface can displaced along the z-axis with respect to the fixed tactile surface.

[0159] **FIGS. 15***a* and **15***b* are perspective views of the top side and bottom side, respectively, of a different embodiment of a novel "flat-E" actuator **360** for use in translating a touchpad. **FIG. 15***c* is a side view of the actuator **360**. Actuator **360** is designed to be very flat and thus may be more appropriate to function within a flat assembly that can be inherently part of the touchpad, touchscreen, or other similar input device. "E-core" actuator topology provides an excellent actuator using minimal magnet material and delivers good force and bandwidth. One disadvantage of the moving magnet actuator is the large depth required ("E" core ferromagnetic piece width can be traded for height to some extent, perhaps reducing the overall depth of the actuator).

[0160] Actuator **360** presents a inventive embodiment of an "E" core that can be used to translate the touchpad (or alternatively to translate a separate surface, as in the embodiments of FIGS. **9-14**). A folded over, flat 3-D embodiment, shown in **FIGS. 15***a*-**15***b*, that may behave substantially like a 2-D case, but with more leakage and non uniform flux at the poles.

[0161] Actuator **360** includes a ferromagnetic piece **362** shaped as an "E", which can be made of a metal such as a ferrous metal or carbon steel plate, and can be a single piece of metal or a lamination. A coil **364** of wire is wound about the central pole of the "E" of the ferromagnetic piece **362**. A floating plastic cage **368** can be positioned on the ferromagnetic piece **362** and can include two or more rollers **370** positioned in apertures in the cage and oriented so that the rollers roll about axes parallel to the axis passing through the coil **364** about which the coil is wound. The cage can be plastic and is floating, i.e. unattached to other components, to allow the rollers to roll. A two-pole magnet **366** is positioned above the poles of the ferromagnetic piece **362** and cage **368** so that there is an air gap between magnet and ferromagnetic piece. The magnet **366** is coupled to the underside (in the orientation of the figures; other orientations are possible) of a backing steel piece **372** which is positioned on top of and contacting the rollers **370**. The rollers thus set the nominal magnetic gap between the magnet and the ferromagnetic piece **362**. The backing steel piece **372** can be rigidly coupled to the touchpad **373**, as shown in **FIG. 15***d*, so that the touchpad, steel piece **372**, and magnet **366** can translate relative to the ferromagnetic piece **362**. For example, the magnet may in some embodiments be a two pole bonded neodymium wafer, and the steel parts may be stamped from single sheets about 1 mm thick. Additional rollers or foam can be used to support the end of the ferromagnetic piece opposite the magnet **366**. The magnet, cage, and backing piece are located to the side of the "E" poles rather than at the front edge as in other E-core type actuators; this allows the actuator of the present invention to be made very flat for laptop and other portable device applications.

[0162] In operation, an electrical current is flowed through the coil **364**, which causes magnetic flux to flow through the ferromagnetic piece in the direction of arrows **374**. In reaction, the steel plate **372** moves in a direction along the axis indicated by arrow **376** (the direction is dependent on the direction of the current in the coil). The rollers **370** rotate to allow the steel plate **372** and magnet **366** to translate relative to the ferromagnetic piece **362**. The floating cage **368** keeps the rollers from moving in undesired directions as they rotate. Also, the magnetic attractive normal forces which occur between ferromagnetic piece **362** and magnet **366** are reacted with the rollers **370**. Other Flat-E related embodiments can include flexure and knife-edge suspensions to react (allow motion from) magnetic normal forces.

[0163] The flat E actuator embodiments described herein can be used to translate the touchpad (or touchscreen) or a separate surface member above or to the side of the touchpad. For example, two flat E actuators can be used in a configuration similar to that of **FIG. 9** to drive the touchpad or surface member in two axes, x and y.

[0164] The actuator **360** can be made very thin in comparison with other actuators, e.g. the assembly can be made approximately 3 or 4 mm thick, less than half as thick as other "E" core actuators. The magnetics design can be iterated for optimal performance. Linearity and detent forces can be traded for thickness.

[0165] Advantages include a planar, thin geometry, which is suitable for laptops, PDA, and other portable devices. The moving magnet approach does not require a large air gap so it may be more attractive for laptop haptic feedback. An "E" core prototype was 10 mm×20 mm×8 mm and is smaller than most DC motors with equivalent force and power consumption. Furthermore, it is a direct drive configuration, so no transmission is required between actuator and touchpad. Efficient, low cost, and easy to manufacture components allow the actuator to be produced cheaply. The actuator is simple to integrate with existing touchpad PCB's and modules. One disadvantage is that magnetic attractive normal forces exist, which may necessitate a suspension. Rollers and/or flexure and knife edge suspensions can be used in some embodiments to react magnetic normal forces.

[0166] The actuator **360** generally provides good bandwidth. Larger (e.g., >1 mm) displacements can be achieved. Those embodiments employing foam to support the opposite end of the ferromagnetic piece have a return spring having a low spring constant, mostly from the foam suspension operated in shear mode. Audible noise may also be reduced by using the foam and/or rollers. While the haptic performance is good, the displacement of the surface is small enough so that when the user is moving a finger over the touchpad to move the cursor over the desktop, the surface displacement does not noticeably affect the cursor motion.

[0167] **FIGS. 16***a* and **16***b* are perspective views of the top side and bottom sides of another embodiment **380** of the "flat-E" actuator of **FIGS. 15***a*-**15***c*. A ferromagnetic piece **382** (or a lamination, in other embodiments) includes an approximate "E" structure and has a coil **384** wound around the E center pole **385**. A two-pole magnet **386** is positioned across the E center pole **385** such that a gap is provided between ferromagnetic piece **382** and magnet, similarly to the embodiment **360**. A metal plate **388** (e.g., steel) is coupled to magnet **386** and is provided parallel to the