can be a pulse, vibration, spatial texture, weight or other physical properties sensible through feeling and touch. The term haptic effect and haptic sensation will be used interchangeably herein.

[0028] The present invention allows a user to manipulate the frequency of the movements between the pole pieces **110**, **112** by adjusting the periodicity of applied input current. The input current means a current passing through the coils **114***a*, **114***b* for generating magnetic fields and magnetic flux in the pole pieces **110**, **112** and across the magnetic gaps **140**, **142**. It should be noted that input currents having different waveform shapes will produce different haptic effect; when an input current is in a square waveform, the haptic effect will be different than when the input current waveform has a sinusoidal shape. In one embodiment, the frequency of haptic effects may have a range between about 40 and about 300 Hertz (Hz).

[0029] An advantage of using such a magnetic circuit with an actuator **100** as described above is to efficiently generate force. Unlike other methods, a permanent magnet is not required to implement the present invention. One could be included to add a small magnetic bias to the magnetic circuit, however. Another advantage of actuator **100** is that it may be made very compact in size. For example, in one embodiment actuator **100** may be about 1.5 inches long, 0.6 inches high and 0.3 inches deep. Depending on the orientation of the actuator **100** with respect to a touch-sensitive panel, it can excite either in-plane or out-of-plane motion between the touch-sensitive panel and the display device for haptic sensation. It should be noted that the L-shaped pole pieces as illustrated in **FIG. 1** represent merely one embodiment and other arrangements of the pole pieces may also be used although the L-shaped pole pieces are believed to be relatively space efficient for this application.

[0030] **FIG. 2** illustrates two alternative embodiments of electromagnet components **200** and **220** capable of generating attractive magnetic force in accordance with the present invention. Electromagnet component **200** includes a C-shaped pole piece **202**, an I-shaped pole piece **204**, and a single coil **206**. Pole pieces **202**, **204** may be made of any suitable ferromagnetic materials as discussed above.

[0031] C-shaped pole piece **202** is placed adjacent to pole piece **204** with two gaps **208**. The width of the gap **208** is approximately 0.5 mm. When the input current passes through the coils **206**, a magnetic flux **210** is generated. Magnetic flux **210** generates the attractive magnetic force between the pole pieces **202**, **204**. The attractive magnetic force causes the pole piece **204** to move closer to the pole piece **202**. Alternatively, the attractive magnetic force can cause pole piece **202** to move closer to pole piece **204** if pole piece **204** is relatively fixed. Haptic effects may be generated by the movements caused by the attractive magnetic force between the pole pieces **202**, **204**.

[0032] Electromagnet component **220** includes an E-shaped pole piece **222**, an I-shaped pole piece **224**, and a coil **226**. Pole pieces **222**, **224** may be constructed as discussed above. E-shaped pole piece **222** is placed adjacent to the I-shaped pole piece **224** with a gap **228**. The width of the gap **228** is approximately 0.5 mm. When the input current passes through coils **226**, magnetic flux lines **230** are generated. Magnetic flux lines **230** cause an attractive magnetic force between pole pieces **222**, **224**. The attractive magnetic force causes pole piece **224** to move closer to pole piece **222** and effectively narrow the width of the gap **228**. In another embodiment, the attractive magnetic force causes the pole piece **222** to move closer to pole piece **224** if pole piece **224** is fastened to housing. A haptic effect may be generated by movements between the pole pieces.

[0033] **FIG. 3** is an actuator **300** illustrating an alternative embodiment of the actuator illustrated in **FIG. 1** in accordance with one embodiment of the present invention. Actuator **300** includes two L-shaped pole pieces **110**, **112**, structural elements **102**, **104**, and biasing element **302**. Pole pieces **110**, **112** are further coupled to coils **114***a*, **114***b* to form magnetic devices. Coils **114***a*, **114***b* are coupled to one or more current sources for causing magnetic flux in pole pieces **110**, **112**.

[0034] Actuator **300** further includes structural elements **102**, **104** and biasing element **302** to form a frame. It should be noted that structural elements **102**, **104** and biasing element **302** can be manufactured at the same time and on a single frame. Alternatively, structural elements **102**, **104** and biasing element **302** may be formed as separate structures that are then assembled together. Structural elements **102**, **104** are fabricated or discussed above to provide physical support for the pole pieces **110**, **112**. Biasing element **302**, which may be formed as described above, is made of an elastic material that may be compressed or stretched within a predefined range. Referring to **FIG. 3**, it should be noted that biasing element **302** may be located anywhere as long as it is coupled with structural elements **102**, **104** and provides its biasing or spring function in opposition to the attractive gap-closing magnetic force of the magnetic devices.

[0035] **FIG. 4** is an alternative embodiment of an actuator **400** in accordance with one embodiment of the present invention. Actuator **400** includes two L-shaped pole pieces **110**, **112**, structural elements **102**, **104**, and biasing elements **402**, **404**. Pole pieces **110**, **112** are further coupled to coils **114***a*, **114***b* to form magnetic devices. Coils **114***a*, **114***b* are coupled to one or more current sources for creating magnetic flux in pole pieces **110**, **112**.

[0036] Actuator **400** further includes structural elements **102**, **104** and biasing elements **402**, **404** to form a frame that allows some movements between the structural elements **102**, **104**. It should be noted that structural elements **102**, **104** and biasing elements **402**, **404** are manufactured separately and they need to be assembled to form a frame. Structural elements **102**, **104** are made of rigid materials, such as plastic, steel, aluminum, and so forth, to provide physical support for the pole pieces **110**, **112**. Biasing elements **402**, **404** may be implemented as discussed above and may be made of elastic materials that can be compressed or stretched within a predefined range. Referring to **FIG. 4**, it should be noted that any type of biasing element may be used as long as it facilitates movement between the pole pieces **110**, **112** and may be arranged to counter the attractive gap-closing force of the magnetic devices.

[0037] **FIG. 5** illustrates a system having an actuator **100** in accordance with one embodiment of the present invention. The system includes a case **502**, a touch-sensitive panel **504**, and an actuator **100**. Actuator **100** includes two L-shaped pole pieces **110**, **112**, structural elements **102**, **104**, and biasing elements **106**, **108**. Pole pieces **110**, **112** are