not intended to be in any way limiting. Other embodiments of the present invention will readily suggest themselves to such skilled persons having the benefit of this disclosure. Reference will now be made in detail to implementations of the present invention as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts.

[0021] In the interest of clarity, not all of the routine features of the implementations described herein are shown and described. It will, of course, be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made in order to achieve the developer's specific goals, such as compliance with application- and business-related constraints, and that these specific goals will vary from one implementation to another and from one developer to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of engineering for those of ordinary skill in the art having the benefit of this disclosure.

[0022] The present invention relates to a user interface system that, in one embodiment, includes a display, an actuator and a touch-sensitive panel. A housing, such as a case, carrier, base, frame or the like may also be used to house the display, actuator and touch-sensitive panel. The actuator includes at least a pair of magnetic devices and at least one biasing element arranged to counter the gap-closing attractive force of the magnetic devices for providing haptic effects.

[0023] Turning now to the figures, **FIG. 1** illustrates an actuator **100** for generating haptic effects in accordance with one embodiment of the present invention. Actuator **100** includes two L-shaped pole pieces **110**, **112**, first and second structural elements **102** and **104** and first and second biasing elements **106** and **108**. Pole pieces **110**, **112**, may be made of standard magnetic steels with high permeability, or other suitable ferromagnetic materials such as soft magnetic materials with high magnetic permeability (e.g., iron, nickel, magnetic alloys) or sintered materials such as ferrite, as are well known to those of ordinary skill in the art. They need not be made of the same material and they are further coupled to coils **114***a*, **114***b* to form electromagnetic devices ("magnetic device"). Coils **114***a*, **114***b*, which may be made of copper or other suitable electric conductors, are coupled to one or more current sources for generating magnetic fields when current passes through the coils **114***a*, **114***b*. In another embodiment one of the pole pieces need not include a coil as long, as it is formed of a ferromagnetic material.

[0024] Actuator **100** further includes structural elements **102**, **104** and first and second biasing elements **106**, **108** to form a frame for the actuator **100**. It should be noted that structural elements **102**, **104** and biasing elements **106**, **108** can be manufactured out of a single piece of material such as metal or plastic. Alternatively, structural elements **102**, **104** and biasing elements **106**, **108** may be manufactured independently. First structural element **102**, as shown in **FIG. 1**, includes appertures **120**, **122**, which are used for coupling or fastening to a housing, a display or a touch-sensitive panel. Similarly, structural element **104** also contains appertures **124**, **126** for similar coupling. Structural elements **102**, **104** are made of reasonably rigid materials, such as plastic, aluminum, and the like, for providing physical support for the pole pieces **110**, **112**. Biasing elements **106**, **108**, which may be springs, flexure springs, flexible blades, flexible members, elastomeric components, foam components, and the like, are made of elastic or relatively flexible materials that can be compressed and/or stretched within a predefined range. In one embodiment the biasing elements **106**, **108** and structural elements **102**, **104** are made of a plastic material with the biasing elements formed to be made thinner (and hence more flexible) than the structural elements.

[0025] Referring again to **FIG. 1**, pole pieces **110** and **112** are coupled to structural elements **102** and **104**, respectively. Pole piece **110** is placed adjacent to pole piece **112** with three magnetic gaps **140**, **142** and **144** between the pole pieces **110**, **112**. The width of the gap **144** situated between the main bodies of the pole pieces **110**, **112** is, in one embodiment, in a range of about 1 to about 5 millimeters ("mm"). The width of the gaps **140**, **142** is in one embodiment, in a range of about 0.25 to about 0.75 mm. Air pockets **130**, **132**, which can be of any shape, provide space for pole pieces **110**, **112** to move. They are not required, however. Because gaps **140**, **142** are much smaller than gap **144** the attractive magnetic force at gaps **140**, **142** dominates over any attractive force across gap **144**.

[0026] In operation, the biasing elements **106**, **108** provide minimal force if there is no current passing through the coils **114** and the actuator is (accordingly) in a relaxed state. Under this no power condition, the actuator attains a first equilibrium position as shown, for example, in **FIG. 1**. When power is applied to coil(s) **114***a*, **114***b* an input current passes through the coil(s) creating magnetic flux lines **150** in the pole pieces **110**, **112** and across gaps **140**, **142**. This process acts to generate an attractive force or attractive magnetic force between the pole pieces **110**, **112** when the coils are wound so that the electromagnetic effects do not cancel one another. The term attractive force and attractive magnetic force are used interchangeably herein. The attractive magnetic force acts against the biasing elements **106**, **108** and pulls the pole pieces **110**, **112** closer together at the gaps **140**, **142**. In accordance with the embodiment shown in **FIG. 1**, under the attractive magnetic force, with structural element **102** held fixed, the pole piece **112** moves in a direction from right to left (as indicated by arrow **138**) toward the pole piece **110**. Pole piece **110**, in this embodiment, may be fastened or secured to structural element **102**, which may be further secured to a housing, touch-sensitive panel or display device. When one of the pole pieces **110**, **112** is displaced enough distance within the gaps **140**, **142**, a second equilibrium position is reached as increasing spring force is applied in an opposite direction by biasing elements **106**, **108**. When power is then reduced or removed, the biasing elements **106**, **108** force the pole pieces **110**, **112** back to their original no-power position, also known as the first equilibrium position as described earlier.

[0027] It should be noted that the attractive force can be manipulated by varying an amount of current passing through the coils **114***a*, **114***b*. Accordingly, the acts of varying the magnitude, duration and pulse repetition of current passing through the coils **114***a*, **114***b* can be used to vary the level and quality of sensation provided by the haptic effect. It should be further noted that the haptic effect, which is also known as tactile, force feedback or haptic sensation,