[0097] The force F generated by the multiple layer piezoelectric bending actuator can be calculated by using the following formula.

$$F=k_2 \cdot d_{31} \cdot T/(W \cdot E \cdot L) \cdot V$$

[0098] k_2: correction constant value

[0099] W: width of the actuator

[0100] E: longitudinal elastic coefficient

[0101] T: thickness of the actuator

[0102] The piezoelectric bending actuator has a fast tactile bandwidth so that it can be used into tactile feedback device. The piezoelectric bending actuator can activate with very small latency so that it can be used in interactive tactile feedback application.

[0103] The multiple layer piezoelectric bending actuator consumes lower power and very low voltage is required. By using the multi-layered piezoelectric bending actuator, it is possible to form the haptic device into small and thin chip.

[0104] The haptic device can generate the force by using the principles of the conservation of momentum, for example an isolated system with no external force, the total momentum of the system is zero. Therefore, when a periodic voltage is applied to the piezoelectric actuator (for example a square wave), it bends, moving attached mass up or down very rapidly. According to the principles of conservation of momentum, when the attached mass moves with momentum pa the entire device would move with the equal momentum pd in opposite direction, generating force on the user hand that holds the device on his/her palm:

$$\vec{P}_a = -\vec{P}_d$$

$$F_d = \frac{d\vec{P}_d}{dt} = -\frac{d\vec{P}_a}{dt} = -m\frac{dv_a}{dt}$$

[0105] Therefore, the user would feel force applied on the users hand that touches the device. The haptic device can act as the haptic display **105** by being installed into the mobile apparatus as described later.

[0106] The haptic display can be formed as a small and thin chip as described above, it can be installed into the mobile apparatus of the other type much smaller than PDAs.

[0107] **FIG. 15A** and **FIG. 15B** show other examples of the multi-layered piezoelectric bending actuator. **FIG. 15A** is an exploded diagram showing an inner structure of the actuator, and **FIG. 15B** is schematic view of the actuator in a completed form.

[0108] The multi-layered piezoelectric bending actuator shown in **FIG. 15A** has 2n-layers of piezoelectric thin films with electrodes sandwiching the films in between. Every other electrode is grouped and connected by a pair of parallel electrode connections as shown in the figure.

[0109] In the instant example, the multi-layered piezoelectric bending actuator includes fourteen layers of piezoelectric (PZT) thin films (=7+7 layers), a thickness of each piezoelectric thin film being 28 μm and the electrode (Ag—Pb) being 4 μm, resulting in a thin beam of about 0.5 mm thickness, 10 mm width and 30 mm length as shown in **FIG. 15B**. The multi-layered piezoelectric bending actuator is provided with electrode leads that are connected to the parallel electrode connections.

[0110] **FIG. 5** depicts the flat shaped information handling apparatus, like PDA, that accommodates the haptic display as depicted in **FIG. 2** and **FIG. 3**. The haptic display is attached so as to actuate a movable part of the mobile apparatus. As shown, it is embedded under the touch panel display. In this case, the haptic display can directly apply the tactile pattern to the user's finger that touches the area where it lies.

[0111] **FIG. 6** also depicts the flat shaped information handling apparatus, like PDA, that accommodates the haptic display as depicted in **FIG. 2** and **FIG. 3**. The haptic display is attached to a movable part of the mobile apparatus. As shown, the movable part is freely suspended on the apparatus body through the springs. The movable part can outwardly transmit the tactile pattern generated by the haptic display.

[0112] **FIG. 7** and **FIG. 8** depict the pen type information handling apparatus that accommodates the haptic display. The pen type apparatus can directly apply the tactile pattern to the user who grasps the pen.

[0113] **FIG. 7** depicts the pen type apparatus where haptic display is installed anywhere inside of the pen and which rapid motion create force impulses that are felt by the user hands.

[0114] **FIG. 8** depicts the pen type apparatus where haptic display is installed under the movable part on the body of the pen. Motions of the haptic actuator move, or push the movable part and these movements are felt by the user holding the pen.

[0115] **FIG. 9** shows the mobile apparatus, that installs the haptic display **105**, applies the force on the user's hand that holds the apparatus.

[0116] The haptic display has a fast tactile bandwidth so that it can be used into tactile feedback device. It can also activate with very small latency so that it can be used in interactive application.

[0117] The haptic device can be attached to the mobile apparatus in two ways.

[0118] First, it can be located anywhere in the mobile apparatus and the whole of the apparatus works as a force/tactile display as shown in **FIGS. 6, 7,** and **8**. In response to the user-input-operation or in accordance with the data processing result, the body of the mobile apparatus gives the user the immediate tactile feedback having a wave of any shape.

[0119] Second, the haptic device can be attached to some movable part of the hand-held apparatus. For example, it can be embedded under the touch panel display screen so that it constitutes the haptic display. If such portion is suspended, only the portion among the body can provide tactile feedback. In this case, the tactile feedback can also have any wave of shape by changing the voltage function of the signal applied to the haptic device.

[0120] **FIG. 10** shows the display screen that embeds the haptic device and applies the immediate tactile feedback directly to the user's finger. By providing the haptic devices