[0120] Rectangular-wave drive signals (including, e.g., square-wave drive signals), such as those described above, are frequently used to convey a strong periodic haptic sensation to a user. These types of sensations conveyed by the rectangular-wave drive signals are sometimes referred to as "square-like" sensations. These square-like sensations, however, are not the only type of sensations desired for haptic feedback. For example, when a haptic device is being driven in the harmonic operational mode, or within the high-frequency range, it may be advantageous to use other drive signal forms because the high-frequency components of such drive signals can be felt and distinguished by users of a haptic device. Some examples of drive signal shapes that can be used to drive a haptic device in harmonic operational mode to produce different haptic sensations than those experienced with a square-wave drive signal including, for example, a saw-like wave, a sinusoid, or the like.

[0121] **FIGS. 18A-18C** are plots showing examples of signals used to drive a haptic device, according to one or more embodiments of the invention. The drive signal shown in **FIG. 18A** is a square wave similar to the transitional frequency range drive signal shown in **FIGS. 17 and 12**C. The drive signals shown in **FIGS. 18B and 18C** are saw-like and sinusoidal waves, respectively. All of the drive signals shown in **FIGS. 18A-18C** are configured with varying duty cycles using similar techniques to those described above in connection with **FIGS. 17 and 12**C with similar effects. Specifically, the drive signals shown in **FIGS. 18A-18C** have a short negative pulse prior to the on-time of each drive signal. This short pulse accomplishes a large initial transition, perceived by a user as a larger magnitude of the haptic feedback, and helps stop or slow down motion of a haptic device from the prior on-time signal (i.e., performs a "braking" function).

[0122] In addition to shaping drive signals used to drive haptic devices capable of providing multiple operational modes (e.g., unidirectional, harmonic, etc.), other techniques of controlling haptic devices are possible. For example, whether a haptic device is acting in a unidirectional or harmonic operational mode, a fast response time that exhibits no perceived lag to a user may be desired. Force applied to a haptic device (e.g., by way of an applied voltage signal), however, sometimes results in a start-up lag that may be detectable by a user. Such start-up lags can detract from the user's haptic experience for some applications.

[0123] The force F applied to a haptic device, such as the haptic device **24** shown in **FIG. 1**, by a haptic device having rotating mass (e.g., a haptic device having an eccentric rotating mass operating in a unidirectional operational mode or a haptic device having a harmonic eccentric rotating mass operating in a unidirectional operational mode) is directly proportional to the square of the angular velocity ω. This force F can be calculated as shown below in Equation 10.

$$F=\epsilon_r\cdot\omega^2 \qquad (10)$$

[0124] In Equation 10 above, ϵ_r is dependent on the size and shape of the rotating mass (i.e., it is dependent on the moment of inertia of the mass). This force F can only be detected by a user above a certain threshold of angular velocity ω. Thus, delays in ramping up the angular velocity ω of the rotating mass result in a delay of the haptic feedback felt by the user. For example, in gaming applications, where the haptic device **24** of the user device **20** uses a large rotating mass, this delay can be as long as approximately 60 ms. Such a significant delay can be felt by a user, and detracts from the haptic sensation experienced by the user. Thus, in some embodiments, decreasing the delay to synchronize the visual display of a haptic feedback triggering event with the corresponding haptic feedback is highly desirable in all operational modes, including, for example, the operational modes corresponding to the three frequency ranges shown in **FIG. 10**.

[0125] **FIG. 19A** is a plot showing an example of a regular-step drive signal **702***a* used to drive a haptic device. According to one or more embodiments of the invention, this regular-step drive signal **702***a* can be referred to as a steady-state signal, or a signal configured to provide steady-state power to a haptic device. Time is shown in milliseconds on the horizontal axis, and relative velocity (of the haptic device) is shown on the vertical axis (which is similarly the case for the remaining figures). The velocity **704***a* of the haptic device that results from the regular-step drive signal **702***a* is also shown on the same plot as a curve. As can be seen in **FIG. 19A**, a delay occurs between the initiation of the regular-step drive signal **702***a* and the achievement of full velocity **704***a* (i.e., the steady-state velocity) of the haptic device. In some circumstances, this delay can be perceived by a user, which may be undesirable in certain applications.

[0126] **FIG. 19B** is a plot showing an example of a signal **702***b* used to drive a haptic device, according to an embodiment of the invention. The lead-in-pulse drive signal **702***b* shown in **FIG. 19B** incorporates a lead-in pulse, and can be used to provide a haptic sensation without a lag time associated with a regular-step drive signal (e.g., the regular-step drive signal **702***a* shown in **FIG. 19A**). In other words, the lead-in-pulse drive signal causes an improved velocity **704***b*, or reduced response time, of the haptic device as shown in **FIG. 19B**. The lead-in-pulse drive signal **702***b* begins with a pulse configured to accelerate the haptic device to full velocity quicker than the regular-step drive signal **702***a* shown in **FIG. 19A**. According to an embodiment of the invention, the lead-in pulse of the lead-in-pulse drive signal **702***b* can be provided by quickly discharging a capacitor when required. Such a capacitor can be trickle charged, for example, so that it is capable of providing the lead-in pulse when it is required.

[0127] In addition to delays associated with initiating tactile forces (e.g., haptic feedback), delays also sometimes exist during termination of such tactile forces (e.g., haptic feedback). For example, because of momentum gained by a rotating mass or other haptic device, termination of a drive signal does not immediately terminate the motion of the device. This response-time lag can be detected by users, which may be undesirable in certain applications. The response-time lag is more pronounced in some applications, such as some video gaming applications that use heavier rotating masses, or other haptic devices having large moments of inertia.

[0128] **FIG. 20A** is a plot showing an example of a regular-step drive signal **802***a* used to drive a haptic device. The plot in **FIG. 20A** shows the regular-step drive signal **802***a*, ends as a step function, thereby terminating steady-state power to the haptic device. As can be seen by the resultant stopping velocity **804***a* shown in **FIG. 20A**, a delay