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(54) **IMPACT TOOL AND CONTROL MODES**

(57) An impact power tool includes a motor, a controller, and an impact mechanism configured to rotationally drive an output spindle. The controller is configured to control power delivered to the motor, during a third phase of operation after a second phase of operation and starting upon expiration of a predetermined time period. The third phase has one or more of a third non-zero target rotational speed, a third duty cycle setting, a third con-

duction band setting, or a third advance angle setting. The controller is configured to control power delivered to the motor, during a fourth phase of operation after the third phase upon detection of a reduction in load on the output spindle or cessation of impacting. The fourth phase has one or more of a fourth non-zero target rotational speed, a fourth duty cycle setting, a fourth conduction band setting, or a fourth advance angle setting.

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Description**TECHNICAL FIELD**

5 **[0001]** This application relates to powered impact tools, such as impact drivers and impact wrenches, and control modes for them.

BACKGROUND

10 **[0002]** Impact drivers and impact wrenches are used for driving threaded fasteners such as screws, nuts, and bolts. If these tools are used at full power, they can overdrive the fasteners and/or strip the heads or threads on the fasteners. If these tools are used at less than full power the speed of application may be too slow or the fastener may not be installed at a desired torque.

SUMMARY

15 **[0003]** In an aspect, an impact power tool includes a housing, a brushless motor received in the housing, a power switch coupled to the housing and actuatable by a user to control power delivery to the motor, a controller configured to control power delivery to the motor in response to actuation of the power switch, an output spindle configured to rotate
20 when the motor is energized, and an impact mechanism configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism is configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. The controller is configured to control the motor with open loop control when a parameter of the motor is above a threshold value and with closed loop control when a parameter of the motor is less than or equal to the threshold value.

25 **[0004]** In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool includes: receiving an input from a user-actuatable power switch corresponding to a desired power to be delivered to the motor; controlling the motor with open loop control when a parameter of the motor is above a threshold value; and controlling the motor with closed loop control when a parameter of the motor is less than or equal to the threshold value.

30 **[0005]** Implementations of the foregoing aspects may include one or more of the following features. The parameter of the motor may be motor speed or output torque. The open loop control may include open loop control. The closed loop control may include closed loop control. The open loop control may include maintaining conduction band and/or advance angle values constant during operation of the motor. The closed loop control may include varying conduction band and/or advance angle values during operation of the motor. During closed loop control, the conduction band and/or advance angle values may be increased as torque on the output spindle increases. During closed loop control, the
35 conduction band and/or advance angle values may reach maximum values upon torque on the output spindle reaching a threshold torque value and may remain constant as torque on the output spindle increases above the threshold torque value. The threshold value may be selected to be optimized for impacting operation.

40 **[0006]** The impact tool may be selectively operable in a first mode of operation wherein the threshold value is a first threshold value and a second mode of operation wherein the threshold value is a second threshold value that is different from the first threshold value. The first threshold value may be selected for optimizing impacting while driving a fastener into a hard joint and the second threshold value may be selected for optimizing impacting while driving a fastener into a soft joint. The parameter of the motor may be motor speed and the first threshold value may be less than the second threshold value.

45 **[0007]** The impact power tool may be selectively operable in a forward mode to drive the motor in a first direction to insert a fastener into a workpiece and in a reverse mode to drive the motor in a second, opposite direction to remove a fastener from a workpiece. In one of the forward mode and the reverse mode, the motor may be controlled with open loop control when a parameter of the motor is above a threshold value and with closed loop control when a parameter of the motor is less than or equal to the threshold value, and in the other of the forward mode and the reverse mode, the power delivered to the motor may be reduced. In at least one of the forward mode and the reverse mode, the controller
50 may detect when impacting begins and shut off or reduce power to the motor a predetermined time period after impacting begins. In at least one of the forward mode and the reverse mode, the controller may detect when impacting stops and shut off or reduce power to the motor a predetermined time period after impacting stops. In at least one of the forward mode and the reverse mode, the controller may detect when impacting begins, pause power delivery to the motor for a predetermined time period after impacting begins, and then resume power delivery to the motor at the end of the pause.
55 In at least one of the forward mode and the reverse mode, the controller may detect when impacting stops, and after impacting stops, may operate the motor using open loop control with a reduced power below a threshold power value regardless of an amount of power selected by the power switch.

[0008] An amount of current delivered to the motor may be maintained to be less than or equal to a current limit. The

current limit may be selected to allow the impact mechanism to impact while inhibiting damage to components of the power tool. The current limit may be selected to prevent the impact mechanism from impacting. If the amount of current reaches the current limit during a cycle of operation of the motor, power to the motor may be turned off or reduced for a duration and then may be restarted. The duration may be a fixed or variable period of time that is greater than one full cycle time. The duration may be a remainder of time in the current operation cycle plus one full additional cycle. The duration may be a remainder of time in the current operation cycle.

[0009] A mode change switch may be coupled to the housing and may be actuatable by a user to select among two or more operation modes of the power tool. Operation modes may include a first mode wherein the threshold value is a first threshold value for optimizing impacting while driving a fastener into a hard joint and a second mode wherein the threshold value is a second threshold value that is different from the first threshold value for optimizing impacting while driving a fastener into a soft joint. Operation modes may include a mode wherein, the controller detects when impacting begins, pauses power delivery to the motor for a predetermined time period after impacting begins, and then resumes power delivery to the motor at the end of the pause. Operation modes may include a mode wherein, the controller detects when impacting begins and shuts off or reduces power to the motor a predetermined time period after impacting begins. Operation modes further may include a mode wherein the controller reduces power delivered to the motor so that the impact mechanism does not begin impacting.

[0010] In another aspect, an impact power tool includes a housing, a brushless motor received in the housing, a power switch coupled to the housing and actuatable by a user to control power delivery to the motor, a controller configured to control power delivery to the motor in response to actuation of the power switch, an output spindle configured to rotate when the motor is energized, and an impact mechanism configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism is configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. The controller is configured to control the motor with open loop control when a parameter of the motor is above a threshold value and with closed loop control when a parameter of the motor is less than or equal to the threshold value. When the motor is being driven in a first direction, the controller is configured to detect when impacting begins, pause power delivery to the motor for a predetermined time period after impacting begins, and then resume power delivery to the motor at the end of the pause.

[0011] In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool includes receiving an input from a user-actuatable power switch; controlling the motor with open loop control when a parameter of the motor is above a threshold value; controlling the motor with closed loop control when a parameter of the motor is less than or equal to the threshold value; and, when the motor is being driven in a first direction, determining when the impact power tool has begun impacting, and pausing power delivery to the motor for a predetermined time period after impacting begins, and then resuming power delivery to the motor at the end of the pause.

[0012] Implementations of the aforementioned aspects may include one or more of the following features. The parameter of the motor may be motor speed or output torque. The open loop control may include open loop control. The closed loop control may include closed loop control. The open loop control may include maintaining conduction band and/or advance angle values constant during operation of the motor. The closed loop control may include varying conduction band and/or advance angle values during operation of the motor. During closed loop control, the conduction band and/or advance angle values may be increased as torque on the output spindle increases. During closed loop control, the conduction band and/or advance angle values may reach maximum values upon torque on the output spindle reaching a threshold torque value and may remain constant as torque on the output spindle increases above the threshold torque value. The threshold value may be selected to be optimized for impacting operation. When the motor is being driven in a second direction opposite the first direction, the controller may detect when impacting stops, and after impacting stops, operate the motor using open loop control with a reduced power below a threshold power value regardless of an amount of power selected by the power switch. An amount of current delivered to the motor may be maintained to be less than or equal to a current limit.

[0013] In another aspect, an impact power tool includes a housing, a brushless motor received in the housing, a power switch coupled to the housing and actuatable by a user to control power delivery to the motor, a controller configured to control power delivery to the motor in response to actuation of the power switch, an output spindle configured to rotate when the motor is energized, and an impact mechanism configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism is configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. The controller is configured to control the motor with open loop control when a parameter of the motor is above a threshold value and with closed loop control when a parameter of the motor is less than or equal to the threshold value. When the motor is being driven in a first direction, the controller is configured to detect when impacting begins and shut off or reduce power to the motor a predetermined time period after impacting begins.

[0014] In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool includes: receiving an input from a user-actuatable power switch; controlling the motor with open loop control when a parameter of the motor is above a threshold value; controlling the motor with closed loop control when a parameter of the motor is

less than or equal to the threshold value; and, when the motor is being driven in a first direction, determining when the impact power tool has begun impacting, and shutting off or reducing power to the motor after impacting begins.

[0015] Implementations of the aforementioned aspects may include one or more of the following features. The parameter of the motor may be motor speed or output torque. The open loop control may include open loop control. The closed loop control may include closed loop control. The open loop control may include maintaining conduction band and/or advance angle values constant during operation of the motor. The closed loop control may include varying conduction band and/or advance angle values during operation of the motor. During closed loop control, the conduction band and/or advance angle values may be increased as torque on the output spindle increases. During closed loop control, the conduction band and/or advance angle values may reach maximum values upon torque on the output spindle reaching a threshold torque value and may remain constant as torque on the output spindle increases above the threshold torque value. The threshold value may be selected to be optimized for impacting operation. When the motor is being driven in a second direction opposite the first direction, the controller may detect when impacting stops and shut off or reduce power to the motor a predetermined time period after impacting stops. An amount of current delivered to the motor may be maintained to be less than or equal to a current limit.

[0016] Implementations of the aforementioned aspects may include one or more of the following features. The tool operation parameter may be one of motor speed, tool output torque, or motor current. The method may comprise, during the second phase of operation, varying the conduction band and advance angle settings during operation of the motor.

[0017] The method may comprise, during closed loop control, increasing at least one of the conduction band value or the advance angle value as torque on the output member increases. The method may comprise, during the second phase of operation, maintaining the motor at a target speed, and, during a third phase of operation, controlling power delivered to the motor with closed loop control when the conduction band and advance angle values have reached their maximum values and torque on the output member continues to increase so that the motor is unable to maintain the target speed.

[0018] The method may further comprise selecting the threshold value to be optimized for impacting operation. The method may further comprise driving the motor in either in a first mode of operation or a second mode of operation. In the first mode of operation, the threshold value is a first threshold value. In the second mode of operation, the threshold value is a second threshold value that is different from the first threshold value.

[0019] The method may further comprise selecting the first threshold value for optimizing impacting while driving a fastener into a hard joint, and selecting the second threshold value for optimizing impacting while driving a fastener into a soft joint. The tool operation parameter of the motor may be motor speed and the first threshold value is less than the second threshold value.

[0020] The method may further comprise, in a first mode, driving the motor in a first direction to insert a fastener into a workpiece and, in a second mode, driving the motor in a second, opposite direction to remove a fastener from a workpiece. The method may further comprise, in one of the first or second mode, limiting power delivered to the motor so that the tool operation parameter is not reached. The method may further comprise detecting when impacting begins and shutting off power to the motor for a predetermined time period after impacting begins regardless of whether the power switch is still actuated.

[0021] The method may further comprise detecting when impacting stops and shutting off power to the motor a predetermined time period after impacting stops regardless of whether the power switch is still actuated. The method may further comprise detecting when impacting begins, pausing power delivery to the motor for a predetermined time period after impacting begins, and then resuming power delivery to the motor at the end of the predetermined time period. The method may further comprise detecting when impacting stops, and after impacting stops, operating the motor using open loop control with a reduced power below a threshold power value regardless of an amount of power selected by the power switch. The method may further comprise maintaining an amount of current delivered to the motor to be less than or equal to a current limit. The method may further comprise selecting the current limit to allow the impact mechanism to impact while inhibiting damage to components of the power tool. The method may further comprise, if the amount of current reaches the current limit during a current delivery cycle, turning off or reducing power to the motor for a duration and then restarting power delivery to the motor.

[0022] The duration may be a fixed period of time that is greater than one full cycle time. The duration may be a remainder of time in the current operation cycle plus one full additional cycle time. The duration may be a remainder of time in the current operation cycle. The method further may comprise selecting the current limit to prevent the impact mechanism from impacting. The method further may comprise actuating a mode change switch that is coupled to the housing to select among two or more operation modes of the power tool. Operation modes of the power tool comprise a first mode wherein the threshold value is a first threshold value for optimizing impacting while driving a fastener into a hard joint and a second mode wherein the threshold value is a second threshold value that is different from the first threshold value for optimizing impacting while driving a fastener into a soft joint. The operation modes may further comprise a third mode wherein, detecting when impacting begins, pausing power delivery to the motor for a predetermined time period after impacting begins, and then resuming power delivery to the motor at the end of the pause. The operation

modes may further comprise a third mode wherein, detecting when impacting begins and shutting off or reducing power to the motor a predetermined time period after impacting begins.

[0023] In another aspect, a power tool includes a housing; a brushless motor received in the housing; a power switch coupled to the housing and actuatable by a user; a controller configured to control power delivery to the motor in response to actuation of the power switch; and an output spindle configured to rotate when the motor is energized. The controller is configured to maintain an amount of current delivered to the motor to be less than or equal to a current limit by turning off or reducing power to the motor for a time period if the current exceeds the current limit and then restarting power delivery to the motor, the time period being greater than the duration of one full current cycle.

[0024] Implementations of the foregoing aspects may include one or more of the following features. The time period may be less than the duration of two full current cycles. The time period is a fixed amount or a variable amount of time. The time period may be a sum of a duration of time remaining in the current cycle plus one full additional current cycle. An impact mechanism may be configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism may be configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. The current limit may be selected to allow the impact mechanism to impact while inhibiting damage to components of the power tool. The current limit may be selected to prevent the impact mechanism from impacting.

[0025] The controller may be further configured to control power delivered to the motor during a first phase of operation with open loop control and a baseline conduction band and advance angle setting when a sensed tool operation parameter is one of above or below a threshold value, and to control power delivered to the motor during a second phase of operation with closed speed loop control and an increased conduction band and advance angle setting when the sensed tool operation parameter is the other of above or below the threshold value.

[0026] The controller may be configured to control power delivered to the motor with a first target rotational speed for a predetermined time period after the controller detects the first impact or that the motor speed has dropped below the speed threshold value, and the controller is configured to control power delivered to the motor with a second target rotational speed after the predetermined time period, the second target rotational speed greater than the first target rotational speed and the first target rotational speed being less than a motor speed when the first impact is detected or when the motor speed drops below the speed threshold value.

[0027] The controller may be configured to control power delivered to the motor with the first target rotational speed using closed loop control with a first conduction band value and a first angle advance value, and the controller is configured to control power delivered to the motor with the second target speed using closed loop control with a second conduction band value and a second angle advance value, wherein at least one of the second conduction band value is greater than the first conduction band value or the second advance angle value is greater than the first advance angle value.

[0028] In another aspect, a method for controlling power delivery to a brushless motor in a power tool includes: receiving an input from a user-actuatable power switch; and maintaining an amount of current delivered to the motor to be less than or equal to a current limit by turning off or reducing power to the motor for a time period if the current exceeds the current limit and then restarting power delivery to the motor, the time period being greater than the duration of one full current cycle.

[0029] Implementations of the foregoing aspects may include one or more of the following features. The time period may be less than the duration of two full current cycles. The time period may be a fixed amount of time. The time period may be a sum of a duration of time remaining in the current cycle plus one full additional current cycle. The method may further include rotationally driving an output spindle by an impact mechanism that is driven by the motor, and selectively applying, by the impact mechanism, rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. The method may further include selecting the current limit to allow the impact mechanism to impact while inhibiting damage to components of the power tool. The method may further include selecting the current limit to prevent the impact mechanism from impacting. The method may further comprise controlling power delivered to the motor during a first phase of operation with open loop control and a baseline conduction band and advance angle setting when a sensed tool operation parameter is one of above or below a threshold value, and controlling power delivered to the motor during a second phase of operation with closed speed loop control and an increased conduction band and advance angle setting when the sensed tool operation parameter is the other of above or below the threshold value.

[0030] The method may further comprise controlling power delivered to the motor with a first target rotational speed for a predetermined time period after the controller detects the first impact or that the motor speed has dropped below the speed threshold value, and controlling power delivered to the motor with a second target rotational speed after the predetermined time period, the second target rotational speed greater than the first target rotational speed and the first target rotational speed being less than a motor speed when the first impact is detected or when the motor speed drops below the speed threshold value.

[0031] The method may further comprise controlling power delivered to the motor with the first target rotational speed using closed loop control with a first conduction band value and a first angle advance value, and controlling power

delivered to the motor with the second target speed using closed loop control with a second conduction band value and a second angle advance value, wherein at least one of the second conduction band value is greater than the first conduction band value or the second advance angle value is greater than the first advance angle value.

[0032] In another aspect, an impact power tool includes a housing, a brushless motor received in the housing, a power switch coupled to the housing and actuatable by a user to control power delivery to the motor, a controller configured to control power delivery to the motor in response to actuation of the power switch, an output spindle configured to rotate when the motor is energized, and an impact mechanism configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism is configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. When the motor is rotated in a first direction, the controller is configured to control the motor with a lower conduction band and/or advance angle for a first predetermined time period and with a higher conduction band and/or advance angle for a second time period after the first predetermined time period, such that greater torque can be generated during the second time period.

[0033] In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool includes: receiving an input from a user-actuatable power switch; controlling the motor with a lower conduction band and/or advance angle for a first predetermined time period; and controlling the motor with a higher conduction band and/or advance angle for a second time period after the first predetermined time period, such that greater torque can be generated during the second time period.

[0034] In another aspect, an impact power tool includes a housing, a brushless motor received in the housing, a power switch coupled to the housing and actuatable by a user to control power delivery to the motor, a controller configured to control power delivery to the motor in response to actuation of the power switch, an output spindle configured to rotate when the motor is energized, and an impact mechanism configured to be driven by the motor and configured to rotationally drive the output spindle. The impact mechanism is configured to selectively apply rotational impacts to the output spindle when a torque on the output spindle exceeds a predetermined amount. When the motor is rotated in a first direction, the controller is configured to control the motor with a higher conduction band and/or advance angle for a first predetermined time period and with a lower conduction band and/or advance angle for a second time period after the first predetermined time period, such that greater torque can be generated during the first time period.

[0035] In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool includes: receiving an input from a user-actuatable power switch; controlling the motor with a higher conduction band and/or advance angle for a first predetermined time period; and controlling the motor with a lower conduction band and/or advance angle for a second time period after the first predetermined time period, such that greater torque can be generated during the first time period.

[0036] Implementations of the foregoing aspects may include one or more of the following features. When the motor is rotated in a second direction opposite the first direction, the controller is configured to control the motor with a higher conduction band and/or advance angle for a third predetermined time period and with a lower conduction band and/or advance angle for a fourth time period after the third predetermined time period, such that greater torque can be generated during the third time period. When the motor is rotated in a second direction opposite the first direction, the controller is configured to control the motor with a lower conduction band and/or advance angle for a third predetermined time period and with a higher conduction band and/or advance angle for a fourth time period after the third predetermined time period, such that greater torque can be generated during the fourth time period.

[0037] When rotated in the first direction, the motor may cause the output spindle to rotate in a direction to insert a fastener into a workpiece. When rotated in the second direction, the motor may cause the output spindle to rotate in a direction to remove a fastener from a workpiece. During the first predetermined time period the controller may operate the motor with open loop control. During the second predetermined time period, the controller may operate the motor with closed loop control. During the third predetermined time period the controller may operate the motor with closed loop control. During the fourth predetermined time period, the controller may operate the motor with open loop control.

[0038] In another aspect, an impact power tool is provided. The impact power tool comprises a housing; a brushless motor received in the housing; a controller configured to control power delivery to the motor in response to actuation of a power switch; an impact mechanism configured to be driven by the motor; and an output spindle configured to receive rotational impacts from the impact mechanism during rotation of the output spindle. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. The controller is configured to control the motor with a first conduction band value and a first advance angle value during a first predetermined time period and to control the motor with a second conduction band value and a second advance angle value after the first predetermined time period. At least one of the second conduction band value is different from the first conduction band value or the second advance angle value is different from the first advance angle value.

[0039] Implementations of the foregoing aspects may include one or more of the following features. The first predetermined time period may factory set or adjustably set by a user. The first predetermined time period may begin upon startup of the motor. The first predetermined time period may begin when the power switch is actuated. The controller may be selectively operable in a forward mode to drive the motor in a first direction to insert a fastener into a workpiece

and in a reverse mode to drive the motor in a second, opposite direction to remove a fastener from a workpiece.

[0040] The controller may be configured to control the motor with the second conduction band value and the second advance angle value for a second predetermined time period. The second predetermined time period may be factory set or adjustably set by a user. The controller may be configured to control the motor with the second conduction band value and the second advance angle value until the power switch is released by a user.

[0041] In the forward mode, at least one of the second conduction band value may be higher than the first conduction band value or the second advance angle value may be higher than the first advance angle value. In the forward mode, at least one of the second conduction band value may be selected among one or more of a plurality of increased conduction band values that are either factory set or adjustably set by a user or the second advance angle value is selected among one or more of a plurality of increased advance angle values that are either factory set or adjustably set by a user.

[0042] The controller may be configured to control the motor with a third conduction band value and a third advance angle value after the second predetermined time period. The third conduction band value may be equal to the first conduction band value and the third advance angle value may be equal to the first conduction band value.

[0043] In the forward mode, the controller may be configured to control the motor with the second conduction band value and the second advance angle value for a second predetermined time period. After the second predetermined time period and in the forward mode, the controller may be configured to control the motor with one or more subsequent conduction band values and one or more subsequent advance angle values during one or more subsequent predetermined time periods. During each subsequent predetermined time period, at least one of the subsequent conduction band value may be greater than the conduction band value during the immediately preceding predetermined time period or the subsequent advance angle value may be greater than the advance angle value during the immediately preceding predetermined time period. Each of the one or more subsequent predetermined time periods may be factory set or adjustably set by a user. Each of the one or more subsequent conduction band values and each of the one or more subsequent advance angle values may be factory set or adjustably set by a user.

[0044] In the reverse mode, at least one of the second conduction band value may be lower than the first conduction band value or the second advance angle value may be lower than the first advance angle value. In the reverse mode, the first predetermined time period may comprise a plurality of consecutive predetermined time periods. During each consecutive predetermined time period, at least one of the conduction band value is less than the immediately preceding conduction band value and the advance angle value is less than the immediately preceding advance angle value.

[0045] The controller may be configured to control the motor with open loop control or closed loop control during each of the first predetermined time period and the second predetermined time period.

[0046] In another aspect, a method for controlling power delivery to a brushless motor in an impact power tool is provided. The method may comprise receiving an input from a user-actuatable power switch corresponding to a desired power to be delivered to the motor; controlling the motor with a first conduction band value and a first advance angle value during a first predetermined time period; and controlling the motor with a second conduction band value and a second advance angle value after the first predetermined time period. At least one of the second conduction band value may be different from the first conduction band value or the second advance angle value may be different from the first advance angle value.

[0047] Implementations of the foregoing aspects may include one or more of the following features. The first predetermined time period may be factory set or adjustably set by a user. The first predetermined time period begins upon startup of the motor. The first predetermined time period begins when the power switch is actuated. The method may include, in a forward mode, driving the motor in a first direction to insert a fastener into a workpiece and, in a reverse mode, driving the motor in a second, opposite direction to remove a fastener from a workpiece. The method may include controlling the motor with the second conduction band value and the second advance angle value for a second predetermined time period. The second predetermined time period may be factory set or adjustably set by a user. The method may include controlling the motor with the second conduction band value and the second advance angle value until the power switch is released by a user. In the forward mode, at least one of the second conduction band value may be higher than the first conduction band value or the second advance angle value may be higher than the first advance angle value. The method may include, in the forward mode, selecting at least one of the second conduction band value among one or more of a plurality of increased conduction band values that are either factory set or adjustably set by a user or selecting the second advance angle value among one or more of a plurality of increased advance angle values that are either factory set or adjustably set by a user.

[0048] The method may include controlling the motor with a third conduction band value and a third advance angle value after the second predetermined time period. The third conduction band value may be equal to the first conduction band value and the third advance angle value may be equal to the first conduction band value.

[0049] The method may include, in the forward mode, controlling the motor with the second conduction band value and the second advance angle value for a second predetermined time period. The method may include, after the second predetermined time period and in the forward mode, controlling the motor with one or more subsequent conduction band

values and one or more subsequent advance angle values during one or more subsequent predetermined time periods. During each subsequent predetermined time period, at least one of the subsequent conduction band value may be greater than the conduction band value during the immediately preceding predetermined time period or the subsequent advance angle value is greater than the advance angle value during the immediately preceding predetermined time period.

[0050] Each of the one or more subsequent predetermined time periods may be factory set or adjustably set by a user. Each of the one or more subsequent conduction band values and each of the one or more subsequent advance angle values may be factory set or adjustably set by a user. In the reverse mode, at least one of the second conduction band value may be lower than the first conduction band value or the second advance angle value may be lower than the first advance angle value.

[0051] In the reverse mode, the first predetermined time period may comprise a plurality of consecutive predetermined time periods. During each consecutive predetermined time period, at least one of the conduction band value may be less than the immediately preceding conduction band value and the advance angle value is less than the immediately preceding advance angle value. The method may include controlling the motor with open loop control or closed loop control during each of the first predetermined time period and the second predetermined time period.

[0052] In another aspect, an impact power tool is provided. The impact power tool comprises a housing; a brushless motor received in the housing; a controller configured to control power delivery to the motor in response to actuation of a power switch; an impact mechanism configured to be driven by the motor; and an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle. The impact mechanism may be configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold.

The controller may be configured to detect a first impact of the rotational impacts or to detect when the motor speed drops below a speed threshold value. The controller is configured to control power delivered to the motor with a first non-zero target rotational speed using closed loop control for a predetermined time period after the controller detects the first impact or that the motor speed has dropped below the speed threshold value. The controller is configured to control power delivered to the motor with a second non-zero target rotational speed using the closed loop control after the predetermined time period. The first non-zero target rotational speed may be less than the second non-zero target rotational speed.

[0053] Implementations of the foregoing aspects may include one or more of the following features. The controller may be configured to control the motor using open loop control for a first time period until the first impact of the rotational impacts is detected or until the motor speed dropping below the speed threshold value is detected. The first time period may begin when the power switch is actuated and ends when the first impact of the impacts is detected or when the motor speed dropping below the speed threshold value is detected.

[0054] During the first time period, the controller may be configured to control the motor using the open loop control and at a constant conduction band value and a constant angle advance value. The predetermined time period may be factory set or adjustably set by a user. The controller may be configured to control the motor to have the first non-zero target rotational speed using the closed loop control and at a constant conduction band value and a constant angle advance value during the predetermined time period.

[0055] After the predetermined time period, the controller may be configured to control the motor at the second non-zero target rotational speed using the closed loop control and at one or more conduction band values and angle advance values for a third one or more subsequent time periods. The one or more subsequent time periods may comprise a first subsequent time period that is predetermined and a second subsequent time period that ends when the power switch is released by the user.

[0056] The one or more subsequent time periods may comprise a plurality of subsequent time periods and the motor is controlled at successively increasing conduction band values or successively increasing angle advance values during each of the successive subsequent time periods. The one or more subsequent time periods may comprise a single subsequent time period that third time period ends when the power switch is released by a user.

[0057] The impact power tool may further comprise a sensor configured to sense motor speed of the motor and/or motor current supplied to the motor. The controller may be configured to monitor changes or variations in the sensed motor speed and/or the sensed motor current to detect the first impact. The sensor may include a torque transducer, a torque sensor, an audio sensor, a vibration sensor, a motor current sensor, and/or a motor speed sensor.

[0058] In an aspect, a method for controlling power delivery to a motor in an impact power tool includes receiving an input from a user-actuatable power switch corresponding to a desired power to be delivered to the motor; detecting a first impact of the rotational impacts or when the motor speed drops below a speed threshold value; controlling power delivered to the motor to have a first non-zero target rotational speed using closed loop control for a predetermined time period after detecting the first impact or after detecting the motor speed has dropped below the speed threshold value; and controlling power delivered to the motor with a second non-zero target rotational speed using closed loop control after the predetermined time period. The first non-zero target rotational speed may be less than the second non-zero target rotational speed.

[0059] Implementations of the foregoing aspects may include one or more of the following features. The method may

include controlling the motor using open loop control for a first time period until the first impact of the rotational impacts is detected or until the motor speed dropping below the speed threshold value is detected. The first time period begins when the power switch is actuated and ends when the first impact of the impacts is detected or when the motor speed dropping below the speed threshold value is detected. The method may include, during the first time period, controlling the motor using the open loop control and at a constant conduction band value and a constant angle advance value. The predetermined time period may be factory set or adjustably set by a user.

[0060] The method may include controlling the motor to have the first non-zero target rotational speed using a constant conduction band value and a constant angle advance value during the predetermined time period. The method may include, after the predetermined time period, controlling the motor at the second non-zero target rotational speed at one or more conduction band values and angle advance values for one or more subsequent time periods. The one or more subsequent time periods may comprise a first subsequent time period that is predetermined and a second subsequent time period that ends when the power switch is released by the user. The one or more subsequent time periods may comprise a plurality of subsequent time periods. The method may include controlling the motor at successively increasing conduction band values or successively increasing angle advance values during each of the successive subsequent time periods. The one or more subsequent time periods may comprise a single subsequent time period that ends when the power switch is released by a user. The method may include sensing motor speed of the motor and/or motor current supplied to the motor, and monitoring changes or variations in the sensed motor speed and/or the sensed motor current to detect the first impact. The sensor may include a torque transducer, a torque sensor, an audio sensor, a vibration sensor, a motor current sensor, and/or a motor speed sensor.

[0061] In another aspect, an impact power tool is provided. The impact power tool comprises a housing; a brushless motor received in the housing; a power switch configured to be actuated by a user; a controller operatively connected with the motor and configured to control power delivery to the motor in response to actuation of the power switch; an impact mechanism configured to be driven by the motor; and an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. The controller is configured to control power delivered to the motor during a first phase of operation starting upon actuation of the power switch. The controller is configured to control power delivered to the motor, during a second phase of operation for a predetermined time period after detection of one or more of the rotational impacts. The second phase of operation has one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting. The controller is configured to control power delivered to the motor, during a third phase of operation after the second phase of operation and starting upon expiration of the predetermined time period. The third phase of operation has one or more of a third non-zero target rotational speed, a third duty cycle setting, a third conduction band setting, or a third advance angle setting, in order to achieve motor power output during the third phase that is greater than motor power output during the second phase. The controller is configured to control power delivered to the motor, during a fourth phase of operation after the third phase of operation upon detection of a reduction in load on the output spindle or cessation of impacting. The fourth phase of operation has one or more of a fourth non-zero target rotational speed, a fourth duty cycle setting, a fourth conduction band setting, or a fourth advance angle setting, in order to achieve motor power output during the fourth phase that is less than the motor power output during the third phase.

[0062] Implementations of the foregoing aspects may include one or more of the following features. At least one of the third non-zero target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting may be greater than at least one of the corresponding second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting.

[0063] The second phase of operation may comprise closed loop control having the second non-zero rotational target speed, the second conduction band setting, and the second advance angle setting, with a variable second duty cycle. The third phase of operation may comprise open loop control having the third duty cycle setting, the third conduction band setting, and the third advance angle setting, with a variable third rotational speed.

[0064] At least one of the fourth target rotational speed, fourth duty cycle setting, fourth conduction band setting, or fourth advance angle setting may be less than at least one of the corresponding third target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting.

[0065] The controller may be configured to control power delivered to the motor, during the first phase of operation, with at least one of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting starting when the power switch is actuated by the user and until the detection of one or more of the rotational impacts.

[0066] At least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting may be less than at least one of the corresponding first non-zero target rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting.

[0067] The at least one of the corresponding first non-zero target rotational speed, first duty cycle setting, first conduction

band setting, or first advance angle setting may achieve a first power output that is greater than the second power output.

[0068] The second conduction band setting and the second angle advance value setting may be constant during the second phase.

[0069] The at least one of the third conduction band setting and the third advance angle setting may be greater than the at least one of the second conduction band setting and the second advance angle setting and successively increase during the third phase.

[0070] The controller may be configured to maintain an amount of current delivered to the motor to be less than or equal to a first current limit, during the first phase and the second phase, by turning off or reducing power to the motor if the current exceeds the first current limit. The controller may be configured to maintain an amount of current delivered to the motor to be less than or equal to a second current limit that is greater than the first current limit, during the third phase, by turning off or reducing power to the motor if the current exceeds the second current limit. In such an implementation, the controller may be configured to turn off or reduce power to the motor for a time period if one of the current limits is exceeded and then restart power delivery to the motor after the time period.

[0071] In another aspect, an impact power tool is provided. The impact power tool comprises a housing; a brushless motor received in the housing; a power switch configured to be actuated by a user; a controller operatively connected with the motor and configured to control power delivery to the motor in response to actuation of the power switch; an impact mechanism configured to be driven by the motor; and an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. The controller is configured to control power delivered to the motor, during a first phase of operation, for a predetermined time period or until detection of one or more of the rotational impacts. The first phase of operation has one or more of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting.

[0072] The controller is configured to control power delivered to the motor, during a second phase of operation after the first phase and starting upon expiration of the predetermined time period or detection of one or more of the rotational impacts. The second phase of operation has one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting, in order to achieve motor power output during the second phase that is greater than motor power output during the first phase.

[0073] The controller is configured to control power delivered to the motor, during a third phase of operation after the second phase, upon detection of a reduction of a load on the output spindle. The third phase of operation has at least one of a third non-zero target rotational speed, a third duty cycle setting, a third conduction band setting, or a third advance angle setting, in order to achieve motor power output during the third phase that is less than the motor power output during the second phase.

[0074] Implementations of the foregoing aspects may include one or more of the following features. At least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting may be greater than at least one of the corresponding first non-zero rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting.

[0075] The at least one of the third target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting may be less than at least one of the corresponding second target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting.

[0076] The first conduction band setting and the first angle advance setting may be constant during the first phase.

[0077] The at least one of the second conduction band setting and the second advance angle setting may be greater than the at least one of the first conduction band setting and the first advance angle setting and successively increase during the second phase.

[0078] The controller may be configured to maintain an amount of current delivered to the motor to be less than or equal to a first current limit, during the first phase, by turning off or reducing power to the motor if the current exceeds the first current limit. The controller may be configured to maintain an amount of current delivered to the motor to be less than or equal to a second current limit that is greater than the first current limit, during the second phase, by turning off or reducing power to the motor if the current exceeds the second current limit. In such an implementation, the controller may be configured to turn off or reduce power to the motor for a time period if one of the current limits is exceeded and then restart power delivery to the motor after the time period.

[0079] In another aspect, an impact power tool is provided. The impact power tool comprises a housing; a brushless motor received in the housing; a controller configured to control power delivery to the motor in response to actuation of a power switch; an impact mechanism configured to be driven by the motor; an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle; and a sensor configured to sense a speed of the motor. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. The controller is configured to determine that a load on the output spindle has been reduced and decrease power delivered to the motor when at least one of: (a) the sensed motor speed exceeds a threshold value for a predetermined number of sample cycles, (b) the sensed motor speed is increasing for

a predetermined number of sample cycles, or (c) an acceleration of the motor is increasing for a predetermined number of sample cycles.

[0080] Implementations of the foregoing aspects may include one or more of the following features. The controller may determine that the sensed motor speed is increasing when the controller determines that a difference between a lowest sensed motor speed during impacting and the sensed motor speed is increasing for a predetermined number of sample cycles.

[0081] The controller may determine that the sensed motor speed is increasing by receiving a signal from the sensor that indicates whether the motor speed exceeds a threshold motor speed and determining that the signal indicates that the motor speed exceeds the threshold motor speed for a predetermined number of consecutive sample cycles. The controller may be configured to control power delivered to the motor prior to determining that a load on the motor has been reduced by controlling current delivered to the motor based on one or more of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting. The controller may be configured to control power delivered to the motor after determining that a load on the motor has been reduced by controlling current delivered to the motor based on one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting. The determination that a load on the output spindle has been reduced may correspond to cessation of impacting.

[0082] Advantages may include one or more of the following. The impact tools and methods may lead to improved control and speed of fastening operation, while increasing power delivered when needed for impacting and reducing the use of unneeded power, thus saving energy, being more efficient, and protecting tool components from damage. These and other advantages and features will be apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0083]

FIG. 1 is a perspective view of an embodiment of an impact tool.

FIG. 2 is a side view of the impact tool of FIG. 1 with a portion of the housing removed.

FIG. 3 is an exploded view of the motor, transmission, and impact mechanism of the impact tool of FIG. 1.

FIG. 4 is a high level block diagram of a control system for the impact tool of FIG. 1.

FIG. 5 is a top view of the user interface of the impact tool of FIG. 1.

FIG. 6 is a graphical illustration of operation of the impact tool in a first control mode.

FIG. 7 is a graphical illustration of operation of the impact tool in a second control mode.

FIG. 8 is a graphical illustration of operation of the impact tool in a third control mode.

FIGS. 9 and 10 are graphical illustrations of operation of the impact tool in a fourth control mode.

FIGS. 11 and 12 are graphical illustrations of operation of the impact tool in a fifth control mode.

FIGS. 13 and 14 are graphical illustrations of operation of the impact tool in a sixth control mode.

FIGS. 15-20 are graphical illustrations of operation of the impact tool in a seventh control mode.

FIGS. 21, 21A and 21B are graphical illustrations of operation of the impact tool in an eighth control mode.

FIGS. 22, 22A and 22B are graphical illustrations of operation of the impact tool in the eighth control mode.

FIGS. 23A and 23B are graphical illustrations of operation of the impact tool in a ninth control mode.

FIGS. 24A and 24B are graphical illustrations of operation of the impact tool in a tenth control mode.

FIGS. 25A and 25B are graphical illustrations of operation of the impact tool in an eleventh control mode.

FIGS. 26A and 26B are graphical illustrations of operation of the impact tool in a twelfth control mode.

FIGS. 27A and 27B are graphical illustrations of operation of the impact tool in which a reduction of load on an output spindle is determined .

DETAILED DESCRIPTION

[0084] Referring to FIGS. 1 and 2, in an embodiment, an impact tool 10 has a housing 12 having a front end portion 14 and a rear end portion 16. The housing 12 includes a motor housing portion 18 that contains a rotary motor 20 and a transmission housing portion 22 that contains a transmission 23 and an impact mechanism 24. In one embodiment, the motor 20 may be a brushless motor. The transmission 23 and the impact mechanism 24 transmit rotary motion from the motor 20 to an output spindle 26, as described in greater detail below. Coupled to the output spindle 26 is a tool holder 29 for retaining a tool bit (e.g., a drill bit or screw driving bit, not shown). The output spindle 26 and the tool holder 29 together define and extend along a tool axis X. As shown, the tool holder 29 includes a hex bit retention mechanism. Further details regarding exemplary tool holders are set forth in commonly-owned U.S. Patent No.: 8,622,401, which is incorporated herein by reference in its entirety.

[0085] Extending downward and slightly rearward of the housing 12 is a handle 30 in a pistol grip formation. The handle 30 has a proximal portion 32 coupled to the housing 12 and a distal portion 34 coupled to a battery receptacle 28. The motor 20 may be powered by an electrical power source, such as a DC power source or battery (not shown), that is coupled to the battery receptacle 28, or by an AC power source. A trigger 36 is coupled to the handle 20 adjacent to the housing 12. The trigger 36 connects the electrical power source to the motor 20 via a controller 40 and may control an amount of power delivery to the motor 20, as described in greater detail below. The trigger 36 may be interchangeably referred to as a power switch or a user-actuable power switch. The controller 40 is configured to control power delivery to the motor 20 in response to actuation of the trigger/power switch 36. A light unit (e.g., an LED) 38 may be disposed on the front end portion 14 of the housing 12, just below the tool holder 29 to illuminate an area in front of the tool holder 29. Alternatively, the light unit may be disposed on a front end portion of the battery receptacle 28. Power delivery to the light unit 38 may be controlled by the trigger 36 and the controller 40, or by a separate switch on the tool.

[0086] Referring also to FIG. 3, in an embodiment, the transmission 23 may be a planetary transmission that includes a pinion or sun gear 44 that is coupled to an output shaft 46 of the motor 20 and that extends along the axis X. One or more planet gears 48 surround and have teeth that mesh with the teeth on the sun gear 44. An outer ring gear 50 is rotationally fixed to the housing 12 and centered on the axis X with its internal teeth meshing with the teeth on the planet gears 48. The planet gears 48 are pivotally coupled to a planet carrier 52. When the motor 20 is energized, it causes the motor output shaft 46 and the sun gear 44 to rotate about the axis X. Rotation of the sun gear 44 causes the planet gears 48 to orbit the sun gear 44 about the axis X, which in turn causes the planet carrier 52 to rotate about the axis X at a reduced speed relative to the rotational speed of the motor output shaft 46. In the illustrated embodiment, only a single planetary stage is shown. It should be understood that the transmission may include multiple planetary stages that may provide for multiple speed reductions, and that each stage can be selectively actuated to provide for multiple different output speeds of the planet carrier. Further, the transmission may include a different type of gear system such as a parallel axis transmission or a spur gear transmission.

[0087] In an embodiment, the impact mechanism 24 may be configured to be driven by the motor 20. The impact mechanism 24 is configured to selectively apply the rotational impacts to the output spindle 26 when a torque on the output spindle 26 exceeds a threshold. That is, the output spindle 26 may be configured to receive rotational impacts from the impact mechanism 24 during rotation of the output spindle 26.

[0088] The impact mechanism 24 may include a cam shaft 54 extending along the tool axis X and fixedly coupled to the planet carrier 52 so that they rotate together. Received over the cam shaft 54 is a cylindrical hammer 56 that is configured to move rotationally and axially relative to the cam shaft 54. The cam shaft 54 also has a front end 58 of smaller diameter that is rotatably received in an axial opening 60 in the output spindle 26. Fixedly coupled to a rear end of the output spindle 26 is an anvil 62 having two radial projections 64. The hammer 56 has two hammer projections 66 on its front end that lie in the same rotational plane as the radial projections 64 of the anvil 62 so that each hammer projection 66 may engage a corresponding anvil projection 64 in a rotating direction.

[0089] Formed on an outer wall of the cam shaft 54 is a pair of rear-facing V-shaped cam grooves 68 with their open ends facing toward the rear end portion 16 of the housing 12. A corresponding pair of forward-facing V-shaped cam grooves (not shown) is formed on an interior wall of the hammer 56 with their open ends facing toward the front end portion 14 of the housing 12. A ball 72 is received in and rides along each of the cam grooves 68, 70 to couple the hammer 56 to the cam shaft 54. A compression spring 74 is received in a cylindrical recess 76 in the hammer 56 and abuts a forward face of the planet carrier 52. The spring 74 biases the hammer 56 toward the anvil 62 so that the so hammer projections 66 engage the corresponding anvil projections 64.

[0090] At low torque levels, the impact mechanism 24 transmits torque to the output spindle 26 in a continuous rotary

motion. When at the low torque levels, the compression spring 74 maintains the hammer 56 in its most forward position so that the hammer projections 66 engage the anvil projections 64. This causes the cam shaft 54, the hammer 56, the anvil 62 and the output spindle to rotate together as a unit about the axis X so that the output spindle 26 has substantially the same rotational speed as the cam shaft 54. This application refers to this operation as rotary operation.

[0091] As the torque increases to a torque transition threshold, the impact mechanism 24 transmits rotational impacts to the output spindle 26. At torque that is greater than or equal to the torque transition threshold, the hammer 56 moves axially rearwardly against the force of the spring 74. This decouples the hammer projections 66 from the anvil projections 64. Thus, the anvil 62 continues to spin freely on its axis without being driven by the motor 20 and transmission 23, so that it coasts to a slightly slower speed. Meanwhile, the hammer 56 continues to be driven at a higher speed by the motor 20 and transmission 23. As this occurs, the hammer 56 moves axially rearwardly relative to the anvil 62 by the movement of the balls 72 rearwardly in the V-shaped cam grooves 68. When the balls 72 reach their rearmost position in the V-shaped cam grooves 68, 70 the spring 74 drives the hammer 56 axially forward with a rotational speed that exceeds the rotational speed of the anvil 62. This causes the hammer projections 66 to rotationally strike the anvil projections 64, imparting a rotational impact to the output spindle 26. This impacting operation repeats as long as the torque on the output spindle 26 continues to exceed the torque transition threshold. This application refers to this operation as impact operation.

[0092] The transition torque threshold for when the impact mechanism 24 transitions from the rotary operation to impact operation is a function of various factors, including the mechanical characteristics of the components of the impact mechanism 24, such as the inertia of the hammer 56 and the force of the spring 74, motor performance characteristics, such as motor speed or acceleration, and external characteristics, such as the tightness of the joint at the workpiece, the fastener, and/or loading of the output spindle. Thus, under different conditions of operation, the transition torque threshold may vary.

[0093] Referring also to FIG. 4, in an embodiment of a control mode, the trigger 36 connects the electrical power source 29 to the motor 20 via the controller 40 that controls power delivery to the motor 20. The controller 40 may include a microprocessor, microcontroller, or other control circuit, a memory device (such as a ROM, RAM, or flash memory device) coupled to the controller 40, and a motor driving circuit (such as an H-bridge circuit, a half-bridge circuit, or an inverter circuit). The motor may be a sensored brushless DC motor with Hall sensors that magnetically sense the magnetic flux of a rotor magnet as the rotor is rotated. That information is sent to the controller 40, which in turn measures the angular position of the rotor based on the sensor information and controls the commutation of the motor according to the angular position.

[0094] The controller 40 may control speed and/or power of the motor using a variety of control modes as described below. Before providing detailed description of these control modes of the impact power tool, some terminology that are being used in the specification are explained below. This terminology should be well known to one of ordinary skill in the art and provided only for ease of the reader.

[0095] Motor speed and/or power may be controlled, e.g., by open loop and/or closed loop control based on input from the Hall sensors, from the selected mode of operation, and from the position of the trigger switch. In addition, motor speed and/or power may be controlled by adjusting the conduction band and/or advance angle (CBAA) values based on a desired power and/or speed output of the motor. Further, when using CBAA in open loop and closed loop speed and/or power control, the speed and/or power may further be adjusted by changing the duty cycle or pulse width modulation (PWM) signal sent to the motor via an inverter circuit. An exemplary implementation of the use of CBAA and PWM in open loop and closed loop speed and power control is disclosed in U.S. Patent Application Publication No. 2018/0248507, which is herein incorporated by reference in its entirety.

[0096] PWM may also be interchangeably referred to as duty cycle. A DC electric motor may be driven using PWM, which cycles the current on and off at a very rapid rate. Each cycle is a duty cycle. If the current is on for the entirety of each cycle, the current delivered to the motor is said to be driven using 100% PWM or duty cycle. If the current is on for only half of each cycle (i.e., off for the other half of each cycle), the power delivered to the motor is said to be driven using 50% PWM or duty cycle. A higher PWM translates to more current and more power delivered to the motor.

[0097] Conduction band and advance angle may be referred to as one or a single entity (i.e., as the conduction band and advance angle (CBAA)) and the single entity has a value/setting, for example, 120/30, 130/35, 140/40, 150/45, 160/50, etc. In another embodiment, the conduction band and the advance angle may be separate entities and the settings/values of these two separate entities may be adjusted or controlled individually/separately. The conduction band setting and the advance angle setting may be implemented in brushless DC motors. Generally, a conduction band setting of 120 degrees and an angle advance setting of 30 degrees are considered baseline for operation of a DC motor. Increasing one or both of the conduction band setting and angle advance setting, e.g., from a conduction band value of 120 degrees and an angle advance value of 30 degrees to a conduction band value of 150 degrees and an angle advance value of 45 degrees may increase the amount of motor output speed and torque for the same PWM.

[0098] When implementing closed loop control, the controller is configured to set a target output speed for the motor, to sense the actual speed of the motor, and to adjust the PWM/duty cycle and/or the CBAA as needed to maintain the

target motor speed. Sometimes, the torque on the motor output may be so high, the motor may not be able to achieve the target speed even with 100% PWM and the largest values for CBAA. When implementing open loop control, the controller is configured to set a fixed PWM/duty cycle and/or CBAA settings to allow the motor speed to vary according to the load. Under no load conditions, the PWM and CBAA may correlate to a motor speed and torque. However, as

[0099] Power tools may also have an absolute current limit, regardless of the PWM/duty cycle setting, type of control (i.e., an open loop control or a closed loop control), the conduction band setting/value or the advance angle setting/value. This is to avoid damage to the electronic and mechanical components.

[0100] It should be understood that other aspects and embodiments of the present patent application may be utilized using a motor assembly without a Hall board, i.e., a BLDC motor that is sensorlessly controlled. Examples of sensorless motor commutation control are six-step trapezoidal commutation using the induced motor voltage signals, sinusoidal control, and field-orientated control. Reference is made to U.S. Patent Application Publication No.: 2020/0389108, which is herein incorporated by reference in its entirety, for a description of sensorless sinusoidal and field-oriented motor control. Also, reference is made to U.S. Patent No.: 10,99,0583, which is herein incorporated by reference in its entirety, for a description of sensorless motor control using the motor induced voltage. An advantage of the Hall board design described in this disclosure is that it allows sensed trapezoidal control of a compact motor that is volumetrically equivalent to a sensorless motor capable of outputting the same power performance. However, other aspects of the present patent application, for example, the nested support plate, the rotor assembly, and the rear end cap design described below, may be implemented for use with a sensorless brushless motor.

[0101] Referring also to FIG. 5, coupled to the battery receptacle 28 is a user interface 42 that includes a light control switch 41 and a mode change switch 43, which provide input to the controller 40, and a plurality of indicia 45 for indicating the selected mode of operation of the tool. The light control switch 41 may be a pushbutton switch that allows the user to select among various modes of operation of the light unit 38, e.g., to vary the duration and intensity of lighting. The mode change switch 42 may be a pushbutton switch that allows the user to select among several operation modes of the motor, as described in further detail below. For example, the mode change switch 42 may allow the user to select among a low speed mode, a high speed mode, a first control mode, and a second control mode. In addition, the trigger 36 may allow the user to adjust the motor speed within a range of powers or motor speeds depending on trigger position (e.g., variable speed operation) or may cause the motor to run at a constant power or constant speed when one or more the motor control modes are selected. Based on the selected mode and/or trigger position, the controller controls the power delivered to the motor by controlling power or by controlling one or more parameters or analogues of power, such as current, voltage, resistance, duty cycle of a pulse width modulation (PWM) signal, motor speed, and/or torque. The term power is used in this application in a generic manner to refer to power or to any of these or other parameters or analogues of power.

[0102] Turning to the control modes, FIG. 6 graphically illustrates a speed torque curve for operation of the motor in a first control mode as selected by mode change switch 43. This mode may also be referred to as a high speed mode or a hard joint mode, as it is designed for driving a fastener into or removing a threaded fastener from a hard joint. Selection of this mode may be indicated by illumination of one of the numbers, e.g., the "2" on the user interface.

[0103] In a first phase of operation (indicated by A1), the brushless motor is controlled using open loop control with constant baseline conduction band (e.g., 120°) and advance angle (e.g., 30°) values. The open loop control allows for the motor to be driven up to a maximum speed ω_{max} (e.g., 24500 rpm). The speed may be varied up to ω_{max} by varying the trigger position and altering the PWM signal up to a duty cycle of 100%. As illustrated, as the output torque T increases, the maximum motor speed will decrease. Initially, the torque may be very low and the motor speed may be close to or at its maximum speed ω_{max} (e.g., 24500 rpm). As the threaded fastener gets tighter, the torque may increase, causing the motor speed to decrease. The relationship between the increase in torque and the decrease in torque T may be linear or may be an exponential, logarithmic, or higher order function. In phase A1, the motor is operated to drive a threaded fastener as quickly as possible before the impact mechanism begins impacting. The impact mechanism may be mechanically tuned so that impacting will begin at approximately a torque value T-impact, which generally corresponds to a motor speed ω_{impact} . Once impacting starts, the torque may continue to increase and the speed may continue to decrease until the speed reaches a transition speed $\omega_{\text{t-1}}$ and/or the torque reaches a transition torque T-1.

[0104] When the controller determines that the speed reaches the transition speed $\omega_{\text{t-1}}$ (e.g., based on signals or speed values received from Hall sensors in the motor or from a rotational speed sensor) and/or the torque reaches the transition torque T-1 (e.g., based on signals received from a torque sensor, such as a torque transducer, or from a current sensor, since current is generally proportional to torque), the controller operates the motor in a second phase of operation (indicated by A2). During the second phase A2, the motor is controlled using closed loop control with variable conduction band and angle advance (CBAA) to attempt to maintain the transition motor speed as the torque continues to increase. For example, the conduction band can vary in steps between 120° and 160° and the angle advance can vary in steps between 30° and 50° based on the detected speed in attempt to maintain a constant speed equal to the transition speed. The transition or target speed $\omega_{\text{t-1}}$ and/or torque T-1 may be empirically selected and optimized for

impacting when driving a fastener into a hard joint (e.g., 17,000 rpm). Eventually, the torque may increase further to a high enough torque T-drop at the highest conduction band and angle advance in the range. During a third phase of operation (indicated by A3), at the highest CBAA the motor is unable to achieve the target speed and the speed will decrease as the torque increases because the CBAA is not increased further. This may continue until the fastener is fully driven as desired into a workpiece.

[0105] During operation of the motor in the high speed mode, as illustrated in FIG. 6, the phases generally, but do not necessarily, occur in a sequence of A1, followed by A2, followed by A3, and the motor speed and torque generally, but do not necessarily, move from left to right along the speed-torque curve. Rather, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may be operable during forward and/or reverse operation of the motor and/or for driving fasteners in both clockwise and counterclockwise directions.

[0106] FIG. 7 graphically illustrates a speed-torque curve for operation of the motor in a second control mode as selected by mode change switch 43. This mode may also be referred to as a low speed mode, as it is designed to provide a lower output torque and slower application speed. Selection of this mode may be indicated by illumination of one of the numbers, e.g., the "1" on the user interface. In this mode, the motor is operated using open loop control or closed loop control with a reduced duty cycle or PWM (e.g., 50% to 60% of maximum PWM) to enable a lower maximum motor speed ω -low (e.g., 13,000 rpm). The speed may be varied up to ω -low by varying the trigger position and altering the PWM signal up to this reduced duty cycle. As in the first control mode, the speed decreases as the torque increases for a given amount of trigger actuation. This mode allows for slower fastening speed, but still has a high enough current limit to enable the impact tool to begin impacting if the torque on the output spindle is high enough. However, if impacting does begin, the beat rate will be slower than in the high speed mode. In some embodiments, the low speed mode may be implemented in both forward and reverse operation of the motor (i.e., when installing or removing a fastener). In other embodiments, the low speed mode may be implemented in forward operation (e.g., when installing a fastener), while the high speed (or hard joint) mode may be implemented in reverse operation to enable faster removal of a fastener.

[0107] During operation of the motor in the low speed mode, as illustrated in FIG. 7, speed and torque generally, but do not necessarily, progress from left to right along the curve. Rather, the speed and torque may move or jump among the curve toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The maximum output speed may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. This mode of operation may be operable during forward and/or reverse operation of the motor and/or for driving fasteners in both clockwise and counterclockwise directions.

[0108] FIG. 8 graphically illustrates a speed-torque curve for operation of the motor in a third control mode as selected by mode change switch 43. This mode may also be referred to as soft joint mode, as it is designed for driving a fastener into or removing a threaded fastener from a joint. Selection of this mode may be indicated by illumination of one of the fastener icons on the user interface.

[0109] In a first phase of operation (indicated by B1), the brushless motor may be controlled using open loop control with constant baseline conduction band (e.g., 120°) and advance angle (e.g., 30°) values. The open loop control allows for the motor to be driven up to a maximum speed ω -max (e.g., 24500 rpm). The speed may be varied up to ω -max by varying the trigger position and altering the PWM signal up to a duty cycle of 100%. As illustrated, as the output torque T increases, the maximum motor speed may decrease. Initially, the torque may be very low and the motor speed may be close to or at its maximum speed ω -max (e.g., 24500 rpm). As the threaded fastener gets tighter, the torque may increase, causing the motor speed to decrease. The relationship between the increase in torque and the decrease in torque T may be linear or may be an exponential, logarithmic, or higher order function. In phase B1, the motor may be operated to drive a threaded fastener as quickly as possible before the impact mechanism begins impacting. The impact mechanism may be mechanically tuned so that impacting will begin at approximately a torque value T-impact, which generally corresponds to a motor speed ω -impact. Once impacting starts, the torque may continue to increase and the speed may continue to decrease until the speed reaches a transition speed ω -2 and/or the torque reaches a transition torque T-2.

[0110] Once the speed reaches the transition speed ω -2 (e.g., based on signals or speed values received from Hall sensors in the motor or from a rotational speed sensor) and/or the torque reaches the transition torque T-2 (e.g., based on signals received from a torque sensor, such as a torque transducer, or from a current sensor, since current is generally proportional to torque), the controller operates the motor in a second phase of operation (indicated by B2). During this second phase, the motor is controlled using closed loop control with variable conduction band and angle advance (CBAA) to attempt to maintain the transition motor speed as the torque continues to increase. For example, the conduction band

can vary in steps between 120° and 160° and the angle advance can vary in steps between 30° and 50° based on the detected speed in attempt to maintain a constant speed equal to the transition speed. The transition or target speed ω -2 and/or torque T-2 may be empirically selected and optimized for impacting when driving a fastener into a soft joint (e.g., 22,000 rpm). The transition or target speed ω -2 for the soft joint mode is higher than the transition or target speed ω -1 for the hard joint mode so that the tool may drive a fastener into a soft joint faster than in a hard joint. Eventually, the torque may increase further to a high enough torque T-drop at the highest conduction band and angle advance in the range. During this third phase of operation (indicated by B3), and the speed will resume decreasing as the torque increases because the CBAA cannot be increased further. This will continue until the fastener is fully driven as desired into a workpiece.

[0111] During operation of the motor in the soft joint mode, as illustrated in FIG. 8, the phases generally, but do not necessarily, occur in a sequence of B1, followed by B2, followed by B3, and the motor speed and torque generally, but do not necessarily, move from left to right along the speed-torque curve. Rather, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may be operable during forward and/or reverse operation of the motor and or for driving fasteners in both clockwise and counterclockwise directions.

[0112] FIGS. 9 and 10 graphically illustrate operation of the motor in a fourth control mode as selected by mode change switch 43. This mode may also be referred to as scaffolding mode, as it is designed for driving a fastener into or removing a threaded fastener from a threaded rod on scaffolding. Selection of this mode may be indicated, e.g., by illumination of one of the fastener icons on the user interface.

[0113] Referring to FIG. 9, forward scaffolding mode operates similarly to the high speed mode, i.e., operating with open loop control with constant CBAA during a first phase C1 until reaching a transition speed ω -3 and/or transition torque T-3 (which may be similar to or different from the transition speed and torque in the high speed mode). Upon reaching the transition speed ω -3 or transition torque T-3, during a second phase C2, the controller operates the motor using closed loop control with variable CBAA to maintain the motor speed at approximately the transition speed ω -3, which has been selected and optimized for impacting when installing a fastener on scaffolding. For example, the conduction band may vary in steps between 120° and 160° and the angle advance can vary in steps between 30° and 50° based on the detected speed in attempt to maintain a constant speed equal to the transition speed. Eventually, the torque may increase further to a high enough torque T-drop at the highest conduction band and angle advance in the range. If this happens, the controller operates the motor in a third phase C3 of operation, and the speed will resume decreasing as the torque increases because the CBAA cannot be increased further.

[0114] The forward scaffolding mode differs from high speed mode in that a timer is started when the tool detects the first impact, which is illustrated as occurring during the first phase C1, but which may also occur during the second phase C2 or the third phase C3. Once the first impact is detected, the timer starts and the controller causes the motor to continue running for a predetermined amount of time x (e.g., 3 seconds to 5 seconds) after detection of the first impact and then shuts off power to the motor, regardless of the speed or torque reached at that time and which operation phase the tool is in, even if the trigger is still pulled. Impacts may be detected by sensing changes or variations in motor speed or current, by a torque transducer or torque sensor, by an audio sensor, by a vibration sensor, and/or by other means known to one of ordinary skill in the art. The time x may be preset in the tool or may be user adjustable (e.g., via a switch, a dial, or an app on an electronic device that communicates wirelessly with the tool). As illustrated, the detection of the first impact occurs during the first phase C1, when the controller is operating the motor with open loop control and constant CBAA. However, the detection of the first impact may occur during any of the phases C1, C2, C3 during operation of the motor. In addition, if the detection of the first impact occurs during any one of the phases of operation, the duration of the timer may not be sufficient for the tool to reach one or more of the other phases. For example, the tool may remain in a single phase or only in two phases during the operation of the motor and/or may move toward the left or the right or back and forth along the illustrated speed-torque curve. This mode is designed to inhibit over-tightening of fasteners on scaffolding.

[0115] During operation of the motor in the forward scaffolding mode, as illustrated in FIG. 9, the phases generally, but do not necessarily, occur in a sequence of C1, followed by C2, followed by C3, and the motor speed and torque generally, but do not necessarily, move from left to right along the speed-torque curve. Rather, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may

be operable during forward and/or reverse operation of the motor and or for driving fasteners in both clockwise and counterclockwise directions.

[0116] Referring to FIG. 10, reverse scaffolding mode operates a similar manner as the forward scaffolding mode, except that the timer runs for a predetermined time period y (e.g., 2 seconds to 4 seconds) upon detecting that impacting has stopped, and shuts off power to the motor at the expiration of the timer regardless of the speed or torque reached or the phase of motor operation that the controller is in, and regardless of whether the trigger is still pulled. The cessation of impacts may be detected by sensing changes or variations in motor speed or current, by a torque transducer or torque sensor, by an audio sensor, by a vibration sensor, and/or by other means known to one of ordinary skill in the art. The time y may be preset in the tool or may be user adjustable (e.g., via a switch, a dial, or an app on an electronic device that communicates wirelessly with the tool). As illustrated, the detection of when impacts have stopped occurs during the third phase C3, when the controller is operating the motor with closed loop control and the maximum CBAA adjustment. However, the detection of when impacts have stopped may occur during any of the phases C1, C2, C3 during operation of the motor. In addition, if the detections of impacting stopping occurs during any one phase of operation, the duration of the timer may not be sufficient for the tool to reach one or more of the other phases. For example, the tool may remain in a single phase or only in two phases during the operation of the motor and/or may move toward the left or the right or back and forth along the illustrated speed-torque curve. The transition speed $\omega-4$ and transition torque T-4 values in the reverse scaffolding mode may be the same as or different than the transition speed $\omega-4$ and transition torque T-4. This mode is designed to inhibit spinning a fastener off of scaffolding too quickly so that it falls off the end of a threaded rod on the scaffolding.

[0117] During operation of the motor in the reverse scaffolding mode, as illustrated in FIG. 10, the phases generally, but do not necessarily, occur in a sequence of C3, followed by C2, followed by C1, and the motor speed and torque generally, but do not necessarily, move from left to right along the speed-torque curve. Rather, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may be operable during forward and/or reverse operation of the motor and or for driving fasteners in both clockwise and counterclockwise directions.

[0118] FIGS. 11 and 12 graphically illustrate operation of the motor in a fifth control mode as selected by mode change switch 43. This mode may also be referred to as precision mode, as it is designed for precision driving a fastener into or removing a fastener from a workpiece. Selection of this mode may be indicated, e.g., by illumination of one of the fastener icons on the user interface.

[0119] Referring to FIG. 11, in precision mode when the tool is driving a fastener into a workpiece (installation precision mode), during a first phase of operation D1, the motor is controlled using open loop control and constant CBAA until the first impact is detected, which is generally before the motor speed reaches a transition speed threshold or transition torque threshold for switching to closed loop control. After the first impact is detected, power to the motor is shut off and rotation of the motor pauses for a predetermined time period t (which may be a factory preset value or may be user adjustable). This pause is long enough to be perceptible to the user (e.g., 0.5 seconds or greater, e.g., up to 2 or 3 seconds) and provides the user time to let go of the trigger if the user does not wish further impacts. After the timer expires, if the trigger is still depressed, the controller resumes operation of the motor using open loop control with constant CBAA during the first phase D1. Once the motor speed and/or output torque reach a transition speed $\omega-5$ and/or a transition torque T-5, during a second phase of operation D2, the controller changes to operating the motor with closed loop control with variable CBAA, similar to in the high speed mode. The threshold values for the transition speed and torque may differ from the previously described modes and may be selected for a particular type of fastening application, and may be factory preset or user adjustable. Eventually, the torque may increase further to a high enough torque T-drop at the highest conduction band and angle advance in the adjustable range of CBAA. If this happens, the controller enters a third phase D3 of operation with closed loop control and constant (maximum) CBAA, so that the speed will decrease as the torque increases because the CBAA cannot be increased further. The detection of when the first impact occurs may usually occur during the first phase D1 but may occur during any of the other phases D2 and D3 (or may not occur at all) and the motor will be paused during the phase when the first impact is detected.

[0120] During operation of the motor in the installation precision mode, as illustrated in FIG. 11, the phases generally, but do not necessarily, occur in a sequence of D1, followed by D2, followed by D3, and the motor speed and torque generally, but do not necessarily, move from left to right along the speed-torque curve. Rather, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user

and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may be operable during forward and/or reverse operation of the motor and for driving fasteners in both clockwise and counterclockwise directions.

[0121] Referring to FIG. 12, in precision mode when the tool is removing a fastener from a workpiece (removal precision mode), during a first phase of operation E1, the motor is controlled using open loop control and constant CBAA until the motor speed reaches a transition speed ω -6 and/or a transition torque T-6. At this point, during a second phase of operation E2, the controller changes to operating the motor with closed loop control with variable CBAA, similar to in the high speed mode. The threshold values for the transition speed and torque may differ from the previously described modes and may be selected for a particular type of fastening application, and may be factory preset or user adjustable. Eventually, the torque may increase further to a high enough torque T-drop at the highest conduction band and angle advance in the adjustable range of CBAA. If this happens, the controller enters a third phase E3 of operation with closed loop control and constant (maximum) CBAA, so that the speed will decrease as the torque increases because the CBAA cannot be increased further. The motor is controlled in the first phase E1, the second phase E2, and/or the third phase E3 until the trigger is released or until the controller detects that impacting has stopped, which occurs at a torque T-impact and/or a motor speed ω -impact.

[0122] After the controller detects that impacting has stopped, the motor is controlled using open loop control with a constant CBAA and a reduced or lower duty cycle or PWM in a fourth phase E4, which is a different speed-torque curve than the speed-torque curve for phases E1, E2, and E3 and which is similar to the speed-torque curve for the low speed mode described above. During the fourth phase E4, the target motor speed may be constant regardless of the amount of trigger travel, thus maintaining a low and substantially constant speed ω -low that is lower than the transition speed ω -6 and the maximum speed ω -max, until the trigger is released, and the speed will decrease as torque increases and vice versa.

[0123] During operation of the motor in the removal precision mode, as illustrated in FIG. 12, the phases generally, but do not necessarily, occur in a sequence of E3, followed by E2, followed by E1, and the motor speed and torque generally, but do not necessarily, move from right to left along the speed-torque curve. Also, the controller generally, but does not necessarily detect that impacts have stopped during phase E1, but it may detect that impacts have stopped during one of phases E2 or E3. Once impacts have stopped, the controller changes to controlling the motor using the speed-torque-curve in phase E4. During operation of the motor in phase E4, the motor speed and torque generally, but do not necessarily, progress from right to left along the curve.

[0124] During all of the removal precision mode, the controller may operate the motor in a single phase or only in two phases during the operation of the motor and/or may move or jump among the phases toward the left or the right or back and forth along the illustrated speed-torque curve as a fastener is driven into or removed from a workpiece and as the torque required to drive the fastener changes based on joint conditions. The transition values of speed and/or torque between phases may be fixed (e.g., factory preset) or adjustable by a user and may be constant or may be dynamically adjustable during operation of the tool. Finally, this mode of operation may be operable during forward and/or reverse operation of the motor and or for driving fasteners in both clockwise and counterclockwise directions.

[0125] FIGS. 13 and 14 graphically illustrate operation of the motor in a sixth control mode, which may be selected by mode change switch 43. This mode may also be referred to as quiet mode, as it is designed to prevent the impact tool from impacting, thus resulting in quieter operation of the impact tool. Selection of this mode may be indicated, e.g., by illumination of one of the fastener icons on the user interface.

[0126] FIG. 13 illustrates the current drawn by the motor over time when an impact tool is used without the quiet mode being active. When the impact tool starts impacting, the current will spike above a threshold I-impact (e.g., approximately 30-35 amps). As shown in FIG. 13, impacting can be prevented from starting by setting a current limit I-quiet that is less than the current above which is drawn when impacting generally starts. By artificially setting this current limit, the tool will be prevented from impacting, resulting in quieter operation of the impact tool (e.g., the impact tool will function as a drill/driver or screwdriver). This current limit I-quiet is generally lower than the current limit I-limit set in the protection mode, which allows the tool to impact. The current limit I-quiet can be implemented using one or more of the implementations described with reference to FIGS. 18-20 below (e.g., turning off or reducing power to the motor for a fixed time period that is greater than one clock cycle, for a variable time period that is greater than one clock cycle, or for the remainder of the current clock cycle).

[0127] FIGS. 15-20 graphically illustrate operation of the motor in a seventh control mode, which may be selected by mode change switch 43 or may continually run in the background simultaneously with any of the other modes described in this application or any other known modes of operation of impact power tools. This mode may also be referred to as protection mode, as it is designed to protect the mechanical and electrical components in the power tool when driving a fastener into or removing a fastener from a workpiece with a joint that is harder than its intended use, while still allowing the impact tool to impact. If a user attempts to use the impact tool to drive a fastener into or remove a fastener from a harder joint than for which it is designed, this mode prevents the motor from drawing too much current, which can lead to damage of the electrical and/or mechanical components of the motor, the switches, the transmission and/or the impact

mechanism. Selection of this mode may be indicated by illumination of one of the fastener icons on the user interface. Alternatively, this mode may continuously run in the background, simultaneously with one or more of the foregoing modes of operation.

[0128] Referring to FIG. 15, when the impact tool is being operated to drive a fastener into or remove a fastener from a the type of joint that corresponds to the selected mode of operation (e.g., a hard joint in high speed mode or a soft joint in soft joint mode), the peak current drawn by the motor (as indicated by the traces on the graphs) generally remains less than a desired peak current threshold I-limit at which the motor will start causing damage to the electrical and/or mechanical components of the tool. Referring to FIG. 16, when the impact tool is being operated to drive a fastener into or remove a fastener from a harder joint than the mode that is selected (e.g., driving a fastener into a very hard joint in high speed mode or driving a fastener into a hard joint in soft joint mode), the peak current drawn by the motor (as indicated by the traces on the graph) may exceed a desired peak current threshold I-limit at which the motor may start causing damage to the electrical and/or mechanical components. Referring to FIG. 17, to address this problem, the motor may be controlled to set a current limit I-limit that is approximately the same as a peak motor current above which the motor may start causing damage to the electrical and mechanical components of the tool. This current limit I-limit may also prevent the tool from automatically shutting down because the motor draws a current that meets or exceeds an even higher absolute current limit that is in place when this mode is not active. This enables the user to continue using the impact tool without a shutdown, while also protecting the tool from excessive current and wear. In this mode, the current drawn by the motor is prevented from exceeding I-limit. However, the current limit is set high enough to enable the impact tool to impact at higher torque levels.

[0129] Referring to FIG. 18, in a first implementation of the protection mode, if the current limit I-limit is reached, the power to the motor power is turned off or reduced for a predetermined time period that is longer than one cycle of the frequency of current being delivered to the brushless motor by the inverter circuit. For example, in the illustrated implementation, the current is delivered at a frequency of 20 kHz, so that one cycle has a length of 50 μ sec. If the current limit is reached at time t0, power delivery to the motor is turned off for a predetermined time period Δt (e.g., 60 μ sec to 1 msec) that is longer than one clock cycle (e.g., 50 μ sec) of the inverter circuit. At time t1 at the end of this time period Δt , power delivery to the motor is resumed with the same frequency. This process is repeated anytime the current limit I-limit is reached. The predetermined time period Δt is long enough to allow the motor to relax so that the current limit will not be exceeded on the next cycle but short enough to be imperceptible to the user. As illustrated, the predetermined time period is greater than the duration of one clock cycle and less than the duration of two clock cycles. However, it should be understood that the predetermined time period may be longer than the duration of two or more clock cycles.

[0130] Referring to FIG. 19, in a second implementation of the protection mode, if the current limit I-limit is reached, the power to the motor power is turned off or reduced for a variable time period Δt that is longer than one cycle of the frequency of current being delivered to the brushless motor by the inverter circuit. The variable time period Δt may be the remaining duration of the clock cycle during which the current limit is reached plus one or more additional clock cycles. For example, in the illustrated implementation, the current is delivered at a frequency of 20 kHz, so that one cycle has a length of 50 μ sec. If the current limit is reached at time t0, power delivery to the motor is turned off for the remainder of the current clock cycle $\Delta t1$ (e.g., 35 μ sec) plus the entirety of the following clock cycle $\Delta t2$ (e.g., 50 μ sec), which together are longer than a single clock cycle (e.g., 50 μ sec) of the inverter circuit. At time t1 at the end of this time period $\Delta t = \Delta t1 + \Delta t2$, power delivery to the motor is resumed with the same frequency. This process is repeated anytime the current limit I-limit is reached. The time period Δt is long enough to allow the motor to relax so that the current limit will not be exceeded on the next cycle but short enough to be imperceptible to the user. As illustrated, the variable time period Δt has a duration that is longer than one clock cycle and less than two clock cycles. However, it should be understood that the duration of the time period Δt may be longer than two or more clock cycles.

[0131] Referring to FIG. 20, in a third implementation of the protection mode, if the current limit I-limit is reached, the power to the motor is turned off for a predetermined time period that is shorter than one cycle of the frequency of current being delivered to the brushless motor by the inverter circuit. For example, in the illustrated implementation, the current is delivered at a frequency of 20 kHz, so that one cycle has a length of 50 μ sec. If the current limit is reached at time t0, power delivery to the motor is turned off for a time period Δt that corresponds to the remainder of the current cycle (e.g., 35 μ sec) and that is shorter than the clock cycle (e.g., 50 μ sec) of the inverter circuit. At time t1 at the end of this time period Δt , power delivery to the motor is resumed with the same frequency. This process is also known as cycle-by-cycle current limiting and is further described in U.S. Patent No.: 10,411,558, which is herein incorporated by reference in its entirety. This process is repeated anytime the current limit I-limit is reached. The predetermined time period Δt is long enough to allow the motor to relax so that the current limit will not be exceeded on the next cycle but short enough to be imperceptible to the user.

[0132] The protection mode may be operable by itself or may be operable with one or more of the other modes of operation described in this application or otherwise known in the art to add a layer of protection to a tool operating on a joint that is harder than the joint for which the motor controls are optimized or designed. This helps enhance the life of the components while not appreciably decreasing application speed.

[0133] FIGS. 21, 21A, 22 and 22A show graphical representations of the operation of the motor 20 in several implementations of an eighth control mode. For example, FIGS. 21 and 21A show graphical representations of the operation of the motor 20 in two implementations of the eighth control mode when the controller 40 is selectively operable in a forward mode to drive the motor 20 in a first direction to insert a fastener into a workpiece. FIGS. 22 and 22A show graphical representations of the operation of the motor 20 in two implementations of the eighth control mode when the controller 40 is selectively operable in a reverse mode to drive the motor in a second, opposite direction to remove a fastener from a workpiece.

[0134] FIGS. 21, 21A, 22 and 22A show various torque-time curves of the operation of the motor 20 in several implementations of the eighth control mode. The torques (e.g., measured in Nm/s) of the motor 20 during its operation in the eighth modes are shown on the left hand side Y-axes of the graphs in FIGS. 21, 21A, 22 and 22A, while the time (i.e., measured in seconds) of the operation of the motor 20 in the eighth modes are shown on the X-axes of the graphs in FIGS. 21, 21A, 22 and 22A.

[0135] FIGS. 21 B and 22B show various speed torque curves of the operation of the motor 20 in several implementations of the eighth control mode. The torques (e.g., measured in Nm/s) of the motor 20 during its operation in the eighth modes are shown on the X-axes of the graphs in FIGS. 21B and 22B, while the motor speed (ω) (e.g., measured in m/s) of the motor 20 during its operation in the eighth modes are shown on the Y-axes of the graphs in FIGS. 21B and 22B.

[0136] The operation of the motor 20 in the eighth control modes may be selected by mode change switch 43. Each of these implementations of the eighth control mode may also be referred to as an implementation of an enhanced mode, as they are designed to enhance power delivered to the motor 20 for or after a predetermined time period after startup of the motor 20 (if the trigger 36 has not been released). As will be clear from the discussions below, in each enhanced mode, there is a change (e.g., either an increase or a decrease) in the conduction band value and/or the advance angle value after one or more predetermined time periods after startup of the motor 20 (if the trigger 36 has not been released).

[0137] For example, in forward enhanced implementations of the eighth control mode (e.g., to drive the motor in the first direction to install a fastener into the workpiece), the conduction band value and/or the advance angle value may start at baseline values (e.g., a conduction band value of 120 degrees and an advance angle value of 30 degrees) and then the conduction band value and/or the advance angle values may be increased to a higher value (e.g., a conduction band value in a range from 130 to 160 degrees and/or the an advance angle value in a range from 35 to 50 degrees) after the predetermined time period, regardless of load conditions.

[0138] In reverse implementations of the eighth control mode (e.g., to drive the motor in the second, opposite direction to remove a fastener from the workpiece), the conduction band value and/or the advance angle value may start at a higher value (e.g., a conduction band value in a range from 130 to 160 degrees and/or an advance angle value in a range from 35 to 50 degrees) and then the conduction band and/or the advance angle may be decreased to a lower or a baseline value (e.g., a conduction band value of 120 degrees and/or an advance angle value of 30 degrees) after a predetermined time period regardless of load conditions.

[0139] Also, as will be clear from the discussions below, the conduction band value and the advance angle value may be individually changed (increased/decreased). And, the controller 40 may operate in open loop control and/or closed loop control in this mode of operation.

[0140] The controller 40 may be configured to control the motor 20 with a first conduction band value and a first advance angle value during a first predetermined time period. The controller 40 is configured to control the motor 20 with a second conduction band value and a second advance angle value after the first predetermined time period.

[0141] At least one of the second conduction band value is different from the first conduction band value or the second advance angle value is different from the first advance angle value. That is, the conduction band value and the advance angle value may be individually changed (increased/decreased). Both the conduction band value and the advance angle value may be controlled/changed together (increased/decreased). In one embodiment, the second conduction band value is different from the first conduction band value, and the second advance angle value is same as the first advance angle value. In another embodiment, the second conduction band value is same as the first conduction band value and the second advance angle value is different from the first advance angle value. In yet another embodiment, the second conduction band value is different from the first conduction band value and the second advance angle value is different from the first advance angle value.

[0142] In one embodiment, the controller 40 may be configured to control the motor 20 with the second conduction band value and the second advance angle value for a second predetermined time period. In another embodiment, the controller 40 may be configured to control the motor 20 with the second conduction band value and the second advance angle value until the power switch 36 is released by the user.

[0143] The controller 40 may be configured to control the motor 20 with a third conduction band value and a third advance angle value after the second predetermined time period. The controller 40 may be configured to control the motor 20 with the third conduction band value and the third advance angle value for a third predetermined time period.

[0144] The first predetermined time period may begin upon startup of the motor 20. The first predetermined time period may begin when the power switch 36 is actuated.

[0145] The first predetermined time period, the second predetermined time period and/or the third predetermined time period may be factory set or adjustably set by a user. The first predetermined time period, the second predetermined time period and/or the third predetermined time period may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The first predetermined time period, the second predetermined time period and/or the third predetermined time period may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10.

[0146] In various implementations, the first and any subsequent predetermined time periods may be in the range of, e.g., 0.5 to 30 seconds.

[0147] The third conduction band value may be different from the second conduction band value and the third advance angle value may be different from the second conduction band value. The third conduction band value may be less than or greater than the second conduction band value and the third advance angle value may be less than or greater than the second conduction band value. For example, in one embodiment, the third conduction band value may be greater than the second conduction band value as long as the second conduction band value was not at the maximum value already.

[0148] The third conduction band value may be equal to the first conduction band value and the third advance angle value may be equal to the first conduction band value. The third conduction band value may be less than or greater than the first conduction band value and the third advance angle value may be less than or greater than the first conduction band value. For example, in one embodiment, the third conduction band value may be greater than the first conduction band value as long as the first conduction band value was not at the maximum value already.

[0149] The controller 40 may be configured to control the motor 20 with open loop control or closed loop control during each of the first predetermined time period and the second predetermined time period. In one embodiment, the controller 40 may be configured to control the motor 20 with the open loop control during the first predetermined time period and the closed loop control during the second predetermined time period. In another embodiment, the controller 40 may be configured to control the motor 20 with the closed loop control during the first predetermined time period and the open loop control during the second predetermined time period. In yet another embodiment, the controller 40 may be configured to control the motor 20 with the open loop control during the first predetermined time period and the open loop control during the second predetermined time period. In yet another embodiment, the controller 40 may be configured to control the motor 20 with the closed loop control during the first predetermined time period and the closed loop control during the second predetermined time period. The controller 40 may be configured to control the motor 20 with the open loop control, the closed loop control or any combination thereof during the third predetermined time period.

[0150] As shown in FIGS. 21, 21A and 21B, the controller 40 may be selectively operable in a forward enhanced mode to drive the motor in the first direction to install a fastener into a workpiece.

[0151] Referring to FIGS. 21, 21A and 21B, in the forward enhanced mode, the first conduction band value CB1 may be a baseline conduction band value and the first advance angle value AA1 may be a baseline advance angle value. For example, the first conduction band value may be 120 degrees and the first advance angle value may be 30 degrees.

[0152] In the forward enhanced mode, at least one of the second conduction band value CB2 may be higher than the first conduction band value CB1 and/or the second advance angle value AA2 may be higher than the first advance angle value AA1. In one embodiment, in the forward enhanced mode, the second conduction band value CB2 is higher than the first conduction band value CB1, while the second advance angle value AA2 is the same as the first advance angle value AA1. In another embodiment, in the forward enhanced mode, the second advance angle value AA2 is higher than the first advance angle value AA1, while the second conduction band value CB2 is the same as the first conduction band value CB1. In yet another embodiment, in the forward enhanced mode, the second conduction band value CB2 is higher than the first conduction band value CB1 and the second advance angle value AA2 is higher than the first advance angle value AA1.

[0153] In one embodiment, as shown in FIG. 21, in one implementation of the forward enhanced mode, the first conduction band value CB1 may be 120 degrees and the first advance angle value AA1 may be 30 degrees and the second conduction band value CB2 may be 130 degrees and the second advance angle value AA2 may be 35 degrees. In another embodiment, the second conduction band value CB2 may be 140 degrees and the second advance angle value AA2 may be 40 degrees. In yet another embodiment, the second conduction band value CB2 may be 150 degrees and the second advance angle value AA2 may be 45 degrees. In yet another embodiment, the second conduction band value CB2 may be 160 degrees and the second advance angle value AA2 may be 50 degrees.

[0154] In the forward enhanced mode, at least one of the second conduction band value CB2 may be selected among one or more of a plurality of increased conduction band values that are either factory set or adjustably set by a user or the second advance angle value is selected among one or more of a plurality of increased advance angle values that are either factory set or adjustably set by a user. The plurality of increased conduction band values and/or the plurality of increased advance angle values may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The plurality of increased conduction band values and/or the plurality of

increased advance angle values may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, the plurality of increased conduction band values may be in the range of 130 and 160 degrees. In one embodiment, the plurality of increased advance angle values may be in the range of 35 and 50 degrees.

[0155] Thus, referring to FIG. 21, when the motor 20 is running in the first direction (e.g., a forward direction for installing the fastener into the workpiece), the motor 20 is controlled to operate in the first phase of operation F1 (with either an open loop control or a closed loop control) and a constant, baseline conduction band value CB1 and/or advance angle value AA1 for the first predetermined time period Δt_1 (e.g., 0.5 to 30 seconds), for example, starting when the trigger switch 36 is actuated. After expiration of this first predetermined time period Δt_1 , the motor 20 is controlled in a second phase F2 (using either an open loop control or a closed loop control) with an increased conduction band value CB2 and/or an increased advance angle value AA2.

[0156] Also, FIG. 21 illustrates various torque-time curves indicating different conduction band and advance angle (CBAA) values during the second phase F2. One or more of these torque-time curves may be selected during the second phase F2. By increasing CBAA values, the control module or controller 40 may be configured to deliver more power to the motor 20, the transmission 23, and the impact mechanism 24 with the goal of delivering more torque output to the output spindle 26. To achieve the torque increase, the additional power can deliver more energy per impact, increase the impacting rate, and/or skip every other impact to maximize the impacting energy. The time duration of operation in the second phase F2 of this enhanced mode may be unlimited until the trigger is released or may be time-limited for a second time period (which may be fixed or user selectable), e.g., to reduce the risk of damage to the electrical and/or mechanical components of the impact tool 10. Upon expiration of this second predetermined time period, if the trigger 36 is still pulled, the controller 40 may return to operation with constant CBAA value for the remainder of time that the trigger 36 is actuated. This implementation may be useful, e.g., in an application where the torque increases over time (e.g., when inserting a fastener into the workpiece).

[0157] As shown in FIG. 21A, in another implementation of the forward enhanced mode, the conduction band value and/or the advance angle value may increase in a stepwise fashion after the first predetermined time period $\Delta t_1'$ during subsequent predetermined time periods (i.e., a second predetermined time period Δt_2 , a third predetermined time period Δt_3 , a fourth predetermined time period Δt_4 , etc.). The controller 40 may be configured to control the motor 20 with the open loop control or the closed loop control during the subsequent predetermined time periods (i.e., a second predetermined time period Δt_2 , a third predetermined time period Δt_3 , a fourth predetermined time period Δt_4 , etc.). That is, the second predetermined time period Δt_2 of the forward enhanced mode in FIG. 21 comprises the subsequent predetermined time periods (i.e., a second predetermined time period Δt_2 , a third predetermined time period Δt_3 , a fourth predetermined time period Δt_4 , etc.) in FIG. 21A. The second predetermined time period Δt_2 of the forward enhanced mode in FIG. 21 may be same as predetermined time period $\Delta t_2'$ in FIG. 21A. The predetermined time period $\Delta t_2'$ in FIG. 21A is cumulative of the subsequent predetermined time periods Δt_2 , Δt_3 and Δt_4 in FIG. 21A.

[0158] Referring to FIG. 21A, in this implementation of the forward enhanced mode, the controller 40 may be configured to control the motor 20 in a first phase of operation F1 (with either an open loop control or a closed loop control) and a constant, baseline conduction band value CB1 and/or a constant, baseline advance angle value AA1 for a first predetermined time period $\Delta t_1'$. After the first predetermined time period $\Delta t_1'$, the controller 40 may be configured to control the motor with a second conduction band value CB2 and a second advance angle value AA2 for a second predetermined time period Δt_2 . After the second predetermined time period Δt_2 and in the forward enhanced mode, the controller 40 may be configured to control the motor 20 with one or more subsequent conduction band values CB3, CB4 and one or more subsequent advance angle values AA3, AA4 during one or more subsequent predetermined time periods Δt_3 , Δt_4 . During each subsequent predetermined time period Δt_3 , Δt_4 , at least one of the subsequent conduction band value CB3, CB4 may be greater than the conduction band value CB2, CB3 during the immediately preceding predetermined time period Δt_2 , Δt_3 or the subsequent advance angle value AA3, AA4 may be greater than the advance angle value AA2, AA3 during the immediately preceding predetermined time period Δt_2 , Δt_3 .

[0159] For example, as shown in FIG. 21A, in another implementation of the forward enhanced mode, the controller 40 may be configured to control the motor 20 with the first conduction band value CB1 of 120 degrees (baseline) and the first advance angle value AA1 of 30 degrees (baseline) for the first predetermined time period $\Delta t_1'$, the controller 40 may then be configured to control the motor 20 with the second conduction band value CB2 of 130 degrees and the second advance angle value AA2 of 35 degrees for the second predetermined time period Δt_2 , the controller 40 may be configured to control the motor 20 with the third conduction band value CB3 of 140 degrees and the third advance angle value AA3 of 40 degrees for the third predetermined time period Δt_3 , and the controller 40 may be configured to control the motor 20 with the fourth conduction band value CB4 of 150 degrees and the fourth advance angle value AA4 of 45 degrees for the fourth predetermined time period Δt_4 . That is, the controller 40 is configured to control the motor with the baseline conduction band value and the baseline advance angle value for the first predetermined time period $\Delta t_1'$, and the controller 40 is then configured to control the motor with the increased conduction band values CB2, CB3, CB4 and the increased advance angle values AA2, AA3, AA4, in a stepwise fashion, for the rest of the predetermined

time periods including the second predetermined time period Δt_2 , the third predetermined time period Δt_3 , and the fourth predetermined time period Δt_4 .

[0160] The one or more subsequent predetermined time periods (including the second predetermined time period Δt_2 , the third predetermined time period Δt_3 , the fourth predetermined time period Δt_4 , etc.) may together be referred to as the second predetermined time period Δt_2 of the forward mode of FIG. 21.

[0161] Each of the one or more subsequent predetermined time periods (including the second predetermined time period Δt_2 , the third predetermined time period Δt_3 , the fourth predetermined time period Δt_4 , etc.) may be factory set or adjustably set by a user. The one or more subsequent predetermined time periods may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The one or more subsequent predetermined time periods may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, each of the one or more subsequent predetermined time periods may be in the range of 0.5 and 30 seconds.

[0162] Each of the one or more subsequent conduction band values and each of the one or more subsequent advance angle values may be factory set or adjustably set by a user. The one or more subsequent conduction band values and/or the one or more subsequent advance angle values may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The one or more subsequent conduction band values and/or the one or more subsequent advance angle values may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, each of the one or more subsequent conduction band values may be in the range of 130 and 160 degrees. In one embodiment, each of the one or more subsequent advance angle values may be in the range of 35 and 50 degrees.

[0163] FIG. 21B shows the same implementation of the forward enhanced mode as shown in FIG. 21. That is, FIG. 21B shows the implementation of the forward enhanced mode as motor speed-torque curves, while FIG. 21 shows the same implementation of the forward enhanced mode as torque-time curves.

[0164] Referring to FIG. 21B, in the first phase of operation (indicated by F1), the motor 20 is controlled (either an open loop control or a closed loop control) at constant baseline conduction band value (e.g., 120°) and constant baseline advance angle value (e.g., 30°) for the first predetermined time period Δt_1 (e.g., 0.5 to 30 seconds), for example, starting when the trigger switch 36 is actuated. After expiration of this first predetermined time period Δt_1 , the motor 20 is controlled in a second phase F2 (using either an open loop control or a closed loop control) with an increased conduction band value CB2 and/or an increased advance angle value AA2. For example, as shown in FIG. 21B, in one implementation of the forward enhanced mode, after expiration of the first predetermined time period Δt_1 , the motor 20 is controlled, using a closed loop control, for the second predetermined time period Δt_2 a) in a second phase F2' with the second conduction band value CB2 may be 130 degrees and the second advance angle value AA2 may be 35 degrees; b) in a second phase F2'' with the second conduction band value CB2 may be 140 degrees and the second advance angle value AA2 may be 40 degrees; c) in a second phase F2''' with the second conduction band value CB2 may be 150 degrees and the second advance angle value AA2 may be 45 degrees; or d) in a second phase F2'''' with the second conduction band value CB2 may be 160 degrees and the second advance angle value AA2 may be 50 degrees.

[0165] In each of these phases of operation F1 and F2 (e.g., F2', F2'', F2''', or F2''') in FIG. 21B, the motor 20 may be allowed to be driven up to a target motor speed ω -target (e.g., 27000 rpm). That is, the motor speed may be varied up to target motor speed ω -target. As illustrated, as the output torque T increases, the motor speed ω will decrease. Initially, the torque T may be very low and the motor speed ω may be close to or at its target motor speed ω -max (e.g., 27000 rpm). As the threaded fastener gets tighter, the torque T may increase, causing the motor speed ω to decrease. The relationship between the increase in torque T and the decrease in torque T may be linear or may be an exponential, logarithmic, or higher order function.

[0166] As shown in FIGS. 22, 22A and 22B, the controller 40 may be selectively operable in a reverse enhanced mode to drive the motor in the second, opposite direction to remove a fastener from a workpiece.

[0167] In the reverse enhanced mode, at least one of the second conduction band value CB2 may be lower than the first conduction band value CB1 and/or the second advance angle value AA2 may be lower than the first advance angle value AA1. In one embodiment, in the reverse enhanced mode, the second conduction band value CB2 is lower than the first conduction band value CB1, while the second advance angle value AA2 is the same as the first advance angle value AA1. In another embodiment, in the reverse enhanced mode, the second advance angle value AA2 is lower than the first advance angle value AA1, while the second conduction band value CB2 is the same as the first conduction band value CB1. In yet another embodiment, in the reverse enhanced mode, the second conduction band value CB2 is lower than the first conduction band value CB1 and the second advance angle value AA2 is lower than the first advance angle value AA1.

[0168] In the reverse enhanced mode, the second conduction band value CB2 may be a baseline conduction band value or the second advance angle value AA2 may be a baseline advance angle value. In the reverse enhanced mode, the second conduction band value CB2 may be 120 degrees or the second advance angle value CB1 may be 30 degrees.

[0169] In the reverse enhanced mode, at least one of the first conduction band values CB1 may be selected among one or more of a plurality of increased conduction band values that are either factory set or adjustably set by a user or at least one of the first advance angle values is selected among one or more of a plurality of increased advance angle values that are either factory set or adjustably set by a user. The plurality of increased conduction band values and/or the plurality of increased advance angle values may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The plurality of increased conduction band values and/or the plurality of increased advance angle values may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, the plurality of increased conduction band values may be in the range of 130 and 160 degrees. In one embodiment, the plurality of increased advance angle values may be in the range of 35 and 50 degrees.

[0170] In one embodiment, as shown in FIG. 22, in one implementation of the reverse enhanced mode, the first conduction band value CB1 may be 130 degrees and the first advance angle value AA1 may be 35 degrees. In another embodiment, the first conduction band value CB1 may be 140 degrees and the first advance angle value AA1 may be 40 degrees. In yet another embodiment, the first conduction band value CB1 may be 150 degrees and the first advance angle value AA1 may be 45 degrees. In yet another embodiment, the first conduction band value CB1 may be 160 degrees and the first advance angle value AA1 may be 50 degrees.

[0171] Thus, referring to FIG. 22, in another implementation of the reverse enhanced mode, when the motor 20 is running in the second opposite direction (e.g., a reverse direction for removing a fastener from a workpiece), the motor 20 is controlled to operate in a first phase of operation G1 (with either open loop control or closed loop control) with an increased conduction band value and/or an increased advance angle value for a predetermined time period $\Delta t1$ (e.g., 0.5 to 30 seconds) starting when the trigger switch 36 is actuated. FIG. 22 illustrates various torque-time curves indicating different CBAA values during the first phase G1. One or more of these torque-time curves may be selected during the first phase G1. By increasing CBAA, the control module or controller 40 delivers more power to the motor 20, the transmission 23, and the impact mechanism 24 with the goal of delivering more torque output to the output spindle 26. To achieve the torque increase, the additional power can deliver more energy per impact, increase the impacting rate, and/or skip every other impact to maximize the impacting energy.

[0172] After expiration of this predetermined time period $\Delta t1$, when torque is generally decreasing, the motor 20 is controlled in a second phase G2 (using either closed loop control or open loop control) with a reduced and/or constant conduction band value and/or a reduced and/or constant advance angle value. By decreasing CBAA, the control module 40 delivers less power to the motor 20, and the motor 20 is more efficient. While the impact mechanism 24 will deliver less torque output to the output spindle 26, this is intended to be used predominantly in loosening applications where the user need the most power at the very beginning of the application. This will allow the tool to do a short burst of high-performance work and then protect itself from damage for the remainder of time the trigger 36 is depressed.

[0173] In the reverse enhanced mode, as shown in FIG. 22A, the controller 40 is configured to control the motor 20 with the increased conduction band values CB1, CB2', CB3 and the increased advance angle values AA1, AA2', AA3, in a stepwise fashion, in the first predetermined time period $\Delta t1$ and the controller 40 is then configured to control the motor 20 with the baseline conduction band value CB2 and the baseline advance angle value AA2 for the second predetermined time period $\Delta t2$. That is, in the reverse enhanced mode, the first predetermined time period $\Delta t1$ comprises a plurality of consecutive predetermined time periods $\Delta t1'$, $\Delta t2'$, $\Delta t3$, and where during each consecutive predetermined time period $\Delta t1'$, $\Delta t2'$, $\Delta t3$, at least one of the conduction band value CB2', CB3 is less than the immediately preceding conduction band value CB1, CB2' and/or the advance angle value AA2', AA3 is less than the immediately preceding advance angle value AA1, AA2'.

[0174] For example, in the illustrated embodiment of FIG. 22A, in the reverse enhanced mode, the controller 40 may be configured to control the motor 20 with the first conduction band value CB1 of 150 degrees and the first advance angle value AA1 of 45 degrees for the first predetermined time period $\Delta t1'$, the controller 40 may then be configured to control the motor 20 with the second conduction band value CB2' of 140 degrees and the second advance angle value AA2' of 40 degrees for the second predetermined time period $\Delta t2'$, the controller 40 may be configured to control the motor 20 with the third conduction band value CB3 of 130 degrees and the third advance angle value AA3 of 35 degrees for the third predetermined time period $\Delta t3$, and the controller 40 may be configured to control the motor 20 with the fourth conduction band value CB2 of 120 degrees (baseline) and the fourth advance angle value AA2 of 30 degrees (baseline) for the fourth predetermined time period $\Delta t2$.

[0175] That is, the controller 40 is configured to control the motor 20 with the increased conduction band values CB1, CB2', CB3 and the increased advance angle values AA1, AA2', AA3, in a stepwise fashion, for the consecutive predetermined time periods including the first predetermined time period $\Delta t1'$, the second predetermined time period $\Delta t2'$, and the third predetermined time period $\Delta t3$, and the controller 40 is then configured to control the motor with the baseline conduction band value CB2 and the baseline advance angle value AA2 for the fourth predetermined time period $\Delta t2$. In the reverse enhanced mode, the first predetermined time period $\Delta t1$ comprises the consecutive predetermined time periods including the first predetermined time period $\Delta t1'$, the second predetermined time period $\Delta t2'$, and the third

predetermined time period Δt_3 . Referring to FIG. 22A, the one or more consecutive predetermined time periods (including the first predetermined time period Δt_1 , the second predetermined time period Δt_2 , the third predetermined time period Δt_3 , etc.) may together be referred to as the first predetermined time period Δt_1 of the reverse enhanced mode.

[0176] In the reverse enhanced mode, each of the one or more consecutive predetermined time periods (including the first predetermined time period Δt_1 , the second predetermined time period Δt_2 , the third predetermined time period Δt_3 , etc.) may be factory set or adjustably set by a user. The one or more consecutive predetermined time periods may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The one or more consecutive predetermined time periods may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, each of the one or more consecutive predetermined time periods may be in the range of 0.5 and 30 seconds.

[0177] In the reverse enhanced mode, each of the one or more consecutive conduction band values and each of the one or more consecutive advance angle values may be factory set or adjustably set by a user. The one or more consecutive conduction band values and/or the one or more consecutive advance angle values may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The one or more consecutive conduction band values and/or the one or more consecutive advance angle values may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10. In one embodiment, each of the one or more consecutive conduction band values may be in the range of 130 and 160 degrees. In one embodiment, each of the one or more consecutive advance angle values may be in the range of 35 and 50 degrees.

[0178] In one embodiment, a method for controlling power delivery to a brushless motor in an impact power tool 10 is provided. The method comprises receiving an input from a user-actuatable power switch 36 corresponding to a desired power to be delivered to the motor 20; controlling the motor 20 with a first conduction band value and a first advance angle value during a first predetermined time period; and controlling the motor 20 with a second conduction band value and a second advance angle value after the first predetermined time period. At least one of the second conduction band value is different from the first conduction band value or the second advance angle value is different from the first advance angle value.

[0179] FIG. 22B shows the same implementation of the reverse enhanced mode as shown in FIG. 22. That is, FIG. 22B shows the implementation of the reverse enhanced mode as motor speed-torque curves, while FIG. 22 shows the same implementation of the reverse enhanced mode as torque-time curves.

[0180] Referring to FIG. 22B, in one implementation of the reverse enhanced mode, when the motor 20 is running in the second opposite direction (e.g., a reverse direction for removing a fastener from a workpiece), the motor 20 is controlled to operate in the first phase of operation G1 (with either open loop control or closed loop control) with an increased conduction band value and/or an increased advance angle value for a predetermined time period Δt_1 (e.g., 0.5 to 30 seconds) starting when the trigger switch 36 is actuated. For example, as shown in FIG. 22B, in one implementation of the reverse enhanced mode, the motor 20 is controlled for the first predetermined time period Δt_1 using a closed loop control a) in a first phase G1' with the first conduction band value CB1 may be 130 degrees and the first advance angle value AA1 may be 35 degrees; b) in a first phase G1'' with the first conduction band value CB1 may be 140 degrees and the first advance angle value AA1 may be 40 degrees; c) in a first phase G1''' with the first conduction band value CB1 may be 150 degrees and the first advance angle value AA1 may be 45 degrees; or d) in a first phase G1'''' with the first conduction band value CB1 may be 160 degrees and the first advance angle value AA1 may be 50 degrees. After expiration of this predetermined time period Δt_1 , the motor 20 is controlled in a second phase G2 (using either closed loop control or open loop control) with a reduced and/or constant conduction band value (e.g., 120 degrees) and/or a reduced and/or constant advance angle value (e.g., 30 degrees) for a second predetermined time period Δt_2 .

[0181] In each of these phases of operation G1 (e.g., G1', G1'', G1''', or G1'') and G2 in FIG. 22B, the motor 20 may be allowed to be driven up to a target motor speed ω_{target} (e.g., 27000 rpm). That is, the motor speed may be varied up to target motor speed ω_{target} . As illustrated, as the output torque T increases, the motor speed ω will decrease. Initially, the torque T may be very low and the motor speed ω may be close to or at its target motor speed ω_{max} (e.g., 27000 rpm). The relationship between the increase in torque T and the decrease in torque T may be linear or may be an exponential, logarithmic, or higher order function.

[0182] FIGS. 23A and 23B graphically illustrate operation of the motor 20 in a ninth control mode, which may be selected by mode change switch 43. This mode may be referred to as precision enhanced mode.

[0183] FIGS. 23A and 23B show various speed-torque-time profiles of the operation of the motor 20 in the ninth control mode. The torques (i.e., measured in Nm/s) of the motor 20 during its operation in the ninth control mode are shown on the right hand side Y-axes of the graph in FIGS. 23A and 23B and the motor speeds (i.e., measured in m/s) of the motor 20 during its operation in the ninth control mode are shown on the left hand side Y-axes of the graph in FIGS. 23A and 23B, while the times of the operation of the motor 20 in the ninth control mode (i.e., measured in seconds) are on the X-axes of the graph in FIGS. 23A and 23B.

[0184] Referring to FIG. 23A, in one embodiment, the controller 40 may be configured to control the motor 20 using either open loop control or closed loop control until a predetermined number of impacts (e.g., a single impact or two impacts) is detected (e.g., at time t_1). The controller 40 may be configured to detect a predetermined number of impacts (e.g., a single impact or two impacts). The controller 40 may be configured to detect a first impact of the rotational impacts of the tool 10.

[0185] Referring to FIG. 23B, in another embodiment, the controller 40 may be configured to detect when the motor speed drops below a speed threshold value and to control the motor 20 using either open loop control or closed loop control or when the motor speed dropping below the speed threshold value is detected (i.e., until a drop in the motor speed below the speed threshold value is detected). The speed threshold value may be factory set or adjustably set by a user. The speed threshold value may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The speed threshold value may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10.

[0186] In one embodiment, the speed threshold value may be set so that it is slightly above the motor speed when the tool 10 ordinarily starts to impact (e.g., as determined by empirical experimentation). Thus, the controller 40 may be configured to switch to closed loop control with a reduced target speed before impacting even starts. This (i.e., detection of when the motor speed is dropping below the speed threshold value) has the advantage of preventing impacting from starting before the target motor speed is decreased, giving greater control to the user.

[0187] Referring to FIG. 23A, the controller 40 is then configured to control the motor 20 to have a first non-zero target rotational speed $\omega-1$ using closed loop control for a predetermined time period Δt after the finite number of impacts is detected. Referring to FIG. 23B, the controller 40 is then configured to control the motor 20 to have a first non-zero target rotational speed $\omega-1$ using closed loop control for a predetermined time period Δt when the motor speed dropping below the speed threshold value is detected (as is the case in FIG. 23B).

[0188] Referring to FIGS. 23A and 23B, the controller 40 is then configured to control the motor 20 to have a second non-zero target rotational speed $\omega-2$ using the closed loop control after the predetermined time period Δt .

[0189] The first non-zero target rotational speed $\omega-1$ may be less than the second non-zero target rotational speed $\omega-1$.

[0190] The controller 40 is configured to control the motor 20 using either open loop control or closed loop control for the first time period P1. Referring to FIG. 23A, the first time period P1 begins when the power switch/trigger 36 is actuated or pulled (i.e., time t_0 seconds) and ends when the first impact of the impacts is detected (i.e., time t_1 seconds). Referring to FIG. 23B, the first time period P1 begins when the power switch/trigger 36 is actuated or pulled (i.e., time t_0 seconds) and ends when the motor speed dropping below the speed threshold value is detected. During the first time period P1, the controller 40 is configured to control the brushless motor 20 using either open loop control or closed loop control and at a constant/baseline conduction band value, e.g., 120 degrees and a constant/baseline angle advance value, e.g., 30 degrees. There is no limit to the duration of the first time period P1.

[0191] In one embodiment, the impact tool 10 includes a sensor configured to sense motor speed of the motor and/or motor current supplied to the motor 20. The controller 40 is configured to monitor changes or variations in the sensed motor speed and/or the sensed motor current to detect the first impact. The sensor may include a torque transducer, a torque sensor, an audio sensor, a vibration sensor, a motor current sensor, and/or a motor speed sensor. The controller 40 is also configured to monitor the sensed motor speed to detect when the motor speed dropping below the speed threshold value.

[0192] In one embodiment, the predetermined time period Δt may be referred to as the second time period P2. During a second time period P2, starting just after the finite (e.g., one) number of impacts is detected at time t_1 or when the motor speed dropping below the speed threshold value is detected, for a predetermined time period Δt until time t_2 (e.g., approximately 0.5 to approximately 4 seconds), the controller 40 may be configured to control the brushless motor 20 to have a first non-zero target rotational speed $\omega-1$ using the closed loop control. During time period P2, the conduction band may have the same baseline value, e.g., 120 degrees and the angle advance may have the same baseline value, e.g., 30 degrees. Alternatively, the conduction band value and/or the advance angle value may be different. In one embodiment, the first non-zero target rotational speed $\omega-1$ may be, e.g., 21,000 rpm. During this time period P2, the actual motor speed may be close to or equal to the first non-zero target rotational speed $\omega-1$ but the actual motor speed may not exceed the first non-zero target rotational speed $\omega-1$ and may vary over time based on joint conditions. The impact mechanism may continue to impact. The output fastener torque may continue to increase, although perhaps at a different or lower rate. The torque increase may be linear or non-linear, and may vary based on the fastener/workpiece interface. The predetermined time period Δt of the second time period P2 may be preset in the tool 10 or may be user adjustable.

[0193] After the predetermined time period Δt , the controller 40 may be configured to control the motor 20 at the second non-zero target rotational speed $\omega-2$ at one or more conduction band values and angle advance values for one or more subsequent time periods. The one or more subsequent time periods may comprise a first subsequent time period that is predetermined and a second subsequent time period that is predetermined and that ends when the power switch 36

is released by the user. The one or more subsequent time periods may comprise a plurality of subsequent time periods and the motor 20 may be controlled at successively increasing conduction band values or successively increasing angle advance values during each of the successive subsequent time periods. As shown in FIGS. 23A and 23B, the one or more subsequent time periods may comprise a single subsequent time period that ends when the power switch is released by a user.

[0194] For example, after the second time period P2 (i.e., predetermined time period Δt) expires at time t_2 , the controller 40 may be configured to control the motor 20 at the second non-zero target rotational speed ω_2 , e.g., using closed loop control and one or more increased conduction band values and angle advance values for a third time period P3.

[0195] During the third time period P3, the second target motor speed ω_2 may be equal to, for example, 27,000 rpm and may be controlled using closed loop control. During time period P3, one or both of the conduction band and/or angle advance may be increased so that the tool 10 can output greater torque. In one embodiment, in the third time period P3, the conduction band value may be increased, e.g., to 160 degrees and the angle advance value may be increased, e.g., to 50 degrees. In another embodiment, in the third time period P3, the conduction band value is any conduction band value that is in the range from 120 to 160 degrees and the angle advance value is increased to any advance angle value that is in the range from 30 to 50 degrees. In an embodiment, the third time period P3 is not limited and ends when the power switch 36 is released by a user. During the third time period P3, the actual motor speed, depending on the fastener/workpiece interface, the actual speed may be less than (perhaps substantially less than) the target speed and may vary linearly or non-linearly over time, as the tool continues to impact. The output fastener torque will continue to increase (although perhaps at a higher rate). At time t_3 seconds, when the fastening operation is complete, the trigger 36 is released and the motor 20 stops. The third time period P3 is similar to the enhanced (eighth) control mode, for example, the second phase of the forward enhanced (eighth) control mode - first direction as described in detail above with respect to FIGS. 21, 21A and 21B.

[0196] In another embodiment, the conduction band value and/or the advance angle value during the third time period P3 may increase in a stepwise fashion after the predetermined time period Δt . That is, the conduction band values can vary in steps between 120° and 160° and the angle advance values can vary in steps between 30° and 50° to control the motor 20 at the second non-zero target rotational speed ω_1 . For example, the third time period may be a predetermined time period and may be followed by one or more subsequent limited or unlimited time period during which one or both of the conduction band value and/or the angle advance value increases, similar to the control method illustrated in FIG. 21A.

[0197] The predetermined time period Δt and/or the third time period P3 and any subsequent time periods may be factory set or adjustably set by a user. The predetermined time period Δt and/or the third time period P3 may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The predetermined time period Δt and/or the third time period P3 may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10.

[0198] The first non-zero target rotational speed ω_1 and/or the second non-zero target rotational speed ω_2 may be factory set or adjustably set by a user. The first non-zero target rotational speed ω_1 and/or the second non-zero target rotational speed ω_2 may adjustably set by the user using an application or an app (on user's phone or computer) associated with the impact tool 10. The first non-zero target rotational speed ω_1 and/or the second non-zero target rotational speed ω_2 may adjustably set by the user using a user/manually actuatable member including a button, a switch, a user interface, a thumb turn wheel, etc. that is disposed on the impact tool 10.

[0199] Exemplary variations of the eighth control mode (i.e., interchangeably referred to as enhanced mode, and as shown in and as described in detail with respect to FIGS. 21-22B)) of the impact power tool are shown and described with respect to a Figs. 24A-24B (i.e., a tenth control mode also referred to as an enhanced mode) and Figs. 25A-25B (i.e., an eleventh control mode also referred to as an enhanced mode). Exemplary variations of the ninth control mode (i.e., interchangeably referred to as precision enhanced mode, and as shown in and as described in detail with respect to FIGS. 23A-23B) of the impact power tool are described with respect to FIGS. 26A-26B (i.e., a twelfth control mode also referred to as a precision enhanced mode).

[0200] Like the eighth control mode (as shown in FIGS. 21-22B) and the ninth control mode (as shown in FIGS. 23A-23B), the tenth control mode (as shown in FIGS. 24A-24B), the eleventh control mode (as shown in FIGS. 25A-25B), and the twelfth control mode (as shown in FIGS. 26A-26B) may be implemented in an impact power tool that generally comprises a housing; a brushless motor received in the housing; a power switch configured to be actuated by a user; a controller operatively connected with the motor and configured to control power delivery to the motor in response to actuation of the power switch; an impact mechanism configured to be driven by the motor; and an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. Each of these features has been described in detail throughout the patent application and, hence, will not be described again here.

[0201] The operation of the motor 20 in the tenth, the eleventh and the twelfth control modes may be selected by the mode change switch 43. Each of the implementations of the tenth, the eleventh and the twelfth control modes may also be referred to as an implementation of an enhanced mode, as they are designed to enhance power delivered to the motor 20 until a detection of a reduction in a load on the output spindle (and/or if the trigger 36 has not been released).

As shown in FIGS. 24A, 25A and 26A, the controller 40 may be selectively operable in a forward enhanced mode to drive the motor 20 in a first direction to insert a fastener into a workpiece (i.e., the controller 40 may be selectively operable for tightening the fastener into the workpiece). As shown in FIGS. 24B, 25B and 26B, the controller 40 may be selectively operable in a reverse enhanced mode to drive the motor 20 in the second, opposite direction to remove a fastener from a workpiece (i.e., the controller 40 may be selectively operable for loosening the fastener into the workpiece).

[0202] FIGS. 24A-24B and 25A-25B show various motor speed-torque-time curves of the operation of the motor 20 in implementations of the tenth and the eleventh control modes, respectively. The motor speeds (ω) (e.g., measured in RPM) during its operation in the tenth and the eleventh control modes, respectively are shown on the left hand side Y-axes of the graphs in FIGS. 24A-25B and the torques (e.g., measured in Nm/s) of the motor 20 during its operation in tenth and the eleventh control modes, respectively are shown on the right hand side Y-axes of the graphs in FIGS. 24A-25B, while the time (i.e., measured in seconds) of the operation of the motor 20 in tenth and the eleventh control modes, respectively is shown on the X-axes of the graphs in FIGS. 24A-25B.

[0203] In the implementations of the tenth control mode of operation, as shown in FIGS. 24A-24B, Phase P1 starts upon trigger 36 actuation and runs for a predetermined time period Δt at baseline target rotational speed, baseline duty cycle/PWM setting, baseline conduction band setting and/or baseline advance angle setting, followed by Phase P2 with enhanced target rotational speed, enhanced duty cycle/PWM setting, enhanced conduction band setting and/or enhanced advance angle setting until the controller 40 detects a reduction in the load on the output spindle (e.g., due to fastener stripping, fastener breakage, tool becoming disengaged from fastener, or fastener breaking away from workpiece) or a cessation of impacting, followed by Phase P3 with reduced target rotational speed, reduced duty cycle/PWM setting, reduced conduction band setting and/or reduced advance angle setting.

[0204] In the eleventh control mode of operation, as shown in FIGS. 25A-25B, Phase P1 starts upon trigger 36 actuation and runs until detection of one or more of the rotational impacts at baseline target rotational speed, baseline duty cycle/PWM setting, baseline conduction band setting and/or baseline advance angle setting, followed by Phase P2 with enhanced target rotational speed, enhanced duty cycle/PWM setting, enhanced conduction band setting, and/or enhanced advance angle setting until the controller 40 detects a reduction in the load on the output spindle (e.g., due to fastener stripping, fastener breakage, tool becoming disengaged from fastener, or fastener breaking away from workpiece) or a cessation of impacting, followed by Phase P3 with reduced target rotational speed, reduced duty cycle/PWM setting, reduced conduction band setting, and/or reduced advance angle setting.

[0205] In non-limiting embodiments, in the implementations of the tenth and the eleventh control modes of operation as shown in FIGS. 24A-25B, phase P1 may use closed loop control with a baseline target rotational speed (e.g., approximately 20000 rpm to approximately 30000 rpm, such as 27000 rpm), phase P2 may use open loop control with an enhanced PWM/duty cycle setting (e.g., approximately 100% duty cycle), an enhanced conduction band setting (e.g., between approximately 120 degrees and approximately 160 degrees, such as 150 degrees) and/or an enhanced advance angle setting (e.g., between approximately 30 degrees and approximately 75 degrees, such as 60 degrees), and phase P3 may use closed loop control with a reduced target rotational speed (e.g., approximately 10000 rpm to approximately 15000 rpm, such as 12000 rpm). In other non-limiting embodiments, in the implementations of the tenth and the eleventh control modes of operation as shown in FIGS. 24A-25B, phase P1 may use closed loop control with baseline target rotational speed (e.g., approximately 20000 rpm to approximately 30000 rpm, such as 27000 rpm), phase P2 may use closed loop control with a higher target rotational speed of (e.g., approximately 25000 rpm to approximately 35000 rpm, such as 30000 rpm), and phase P3 may use closed loop control with reduced target rotational speed (e.g., approximately 10000 rpm to approximately 15000 rpm, such as 12000 rpm). In yet other non-limiting embodiments, in the implementations of the tenth and the eleventh control modes of operation as shown in FIGS. 24A-25B, phase P1 may use open loop control with a baseline PWM/duty cycle setting (e.g., approximately 80% to 100% duty cycle), a baseline conduction band setting (e.g., approximately 120 degrees) and a baseline advance angle setting (e.g., approximately 60 degrees), phase P2 may use open loop control with a baseline or enhanced PWM/duty cycle setting (e.g., approximately 90% to 100% duty cycle), an enhanced conduction band setting (e.g., between approximately 120 degrees and approximately 160 degrees, such as 150 degrees) and/or enhanced advance angle setting (e.g., between approximately 30 degrees and approximately 75 degrees, such as 60 degrees), and phase P3 may use open loop control with reduced PWM/duty cycle setting (e.g., between approximately 30% and 75% duty cycle, a baseline or reduced conduction band setting (e.g., approximately 120 degrees) and/or a baseline reduced advance angle setting of (e.g., approximately 30 degrees).

[0206] Non-limiting examples of the implementations of the tenth and the eleventh control modes of operation as shown in FIGS. 24A-24B and 25A-25B are now explained in detail.

[0207] The controller 40 is configured to control power delivered to the motor 20, during a first phase of operation, for a predetermined time period Δt or until detection of one or more of the rotational impacts. The first phase of operation

includes one or more of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting.

[0208] In the implementations of FIGS. 24A-24B, the baseline/first phase P1 starts when the power switch/trigger 36 is actuated by the user and until the expiration of the predetermined time period Δt . The predetermined time period Δt may be factory set or adjustably set by the user. The predetermined time period Δt may begin upon startup of the motor 20 and/or when the power switch 36 is actuated by the user.

[0209] In the implementations of FIGS. 25A-25B, the baseline/first phase P1 starts when the power switch/trigger 36 is actuated by the user and until the detection of one or more of the rotational impacts.

[0210] The first phase of operation may interchangeably referred to as Phase 1/P1 or baseline phase. The baseline phase P1 may be between the time t_0 and time t_1 as shown in FIGS. 24A-25B. The baseline phase P1 occurs prior to the enhanced/second phase P2.

[0211] The first phase P1 of operation comprises closed loop control having the first non-zero rotational target speed, the first conduction band setting, and the first advance angle setting, with a variable first duty cycle.

[0212] As shown in FIGS. 24A-24B, the controller 40 may be configured to control power delivered to the motor 20, during the baseline/first phase P1, with at least one of the first non-zero target rotational speed, first duty cycle setting, first conduction band setting or first angle advance setting when the power switch 36 is actuated by the user and until the expiration of the predetermined time period Δt .

[0213] As shown in FIGS. 25A-25B, the controller 40 may be configured to control power delivered to the motor 20, during the baseline/first phase P1, with at least one of the first non-zero target rotational speed, first duty cycle setting, first conduction band setting or first angle advance setting when the power switch 36 is actuated by the user and until the detection of one or more of the rotational impacts.

[0214] The first conduction band setting and the first angle advance setting are constant during the first phase P1.

[0215] In this control mode (which are the same in forward and reverse), at time t_0 , the trigger 36 is pulled and the controller 40 is configured to set a first relatively high target motor rotational speed $w-1$, a conduction band setting of 120 degrees and an advance angle setting of 30 degrees, and closed loop control. When tightening a fastener, as shown in Fig. 25A, the actual motor speed rapidly ramps up to the target motor rotational speed, prior to the fastener seating. The actual speed is maintained close to the target motor rotational speed, with possibly some decline for period P1 until time t_1 , when impacting of the impact power tool is detected as shown in FIGS. 25A-25B or when the predetermined time period expires as shown in FIGS. 24A-24B. When loosening a fastener, as shown in Fig. 25B, the actual motor speed rapidly ramps up toward the target motor rotational speed, prior to the tool beginning to impact at time t_1 . The target speed may not be achieved prior to the tool beginning to impact.

[0216] The controller 40 is configured to control power delivered to the motor 20, during a second phase P2 of operation after the first phase P1 and starting upon expiration of the predetermined time period Δt or detection of one or more of the rotational impacts. The second phase of operation includes one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting, in order to achieve motor power output during the second phase that is greater than motor power output during the first phase P1.

[0217] The second phase of operation may be interchangeably referred to as phase 2/P2, as enhanced phase of operation. The enhanced/second phase P2 may be between the time t_1 and time t_2 as shown in FIGS. 24A and 25B. The enhanced/second phase P2 starts after the baseline/first phase P1.

[0218] At time t_1 , upon expiration of the time period Δt or upon detection of one or more impacts, the controller 40 provides for enhanced power to the motor 20 by increasing the duty cycle to 100% (if not already there) and increasing conduction band setting, e.g., to 160 degrees and the advance angle setting, e.g., to 50 degrees. This change provides a boost in speed and current. This is generally done using open loop control with 100% duty cycle; however, the controller 40 could execute closed loop control. In either type of control, the output speed of the motor 20 will tend to increase at the start of enhanced/second period P2 and then decrease as torque continues to increase. Because this requires greater current, the absolute current limit may be increase temporarily to a second current limit.

[0219] The enhanced/second phase P2 starts upon expiration of the predetermined time period Δt in FIGS. 24A-24B. The predetermined time period Δt expires or ends at time t_1 as shown in FIGS. 24A and 24B.

[0220] The enhanced/second phase P2 starts upon detection of one or more of the rotational impacts in FIGS. 25A-25B. The detection of one or more of the rotational impacts are shown at time t_1 (as impact detected) in FIGS. 25A-25B. The detection of one or more of the rotational impacts are described in detail in earlier embodiments described in this patent application and, hence, will not be described again here.

[0221] The at least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting of the second phase P2 is greater than at least one of the corresponding first non-zero rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting of the first phase P1.

[0222] During the enhanced/second phase P2, the at least one of the second conduction band setting and the second advance angle setting of the enhanced/second phase P2 are greater than the at least one of the first conduction band

setting and the first advance angle setting of the baseline/first phase P1 and may successively increase during the enhanced/second phase P2.

[0223] For example, in enhanced/second phase P2 and in a forward enhanced mode, the controller 40 may be configured to control the motor 20 with a second conduction band value and a second advance angle value for a second predetermined time period. After the second predetermined time period and in the forward enhanced mode, the controller 40 may be configured to control the motor 20 with one or more subsequent conduction band values and one or more subsequent advance angle values during one or more subsequent predetermined time periods. During each subsequent predetermined time period, at least one of the subsequent conduction band value may be greater than the conduction band value during the immediately preceding predetermined time period or the subsequent advance angle value may be greater than the advance angle value during the immediately preceding predetermined time period.

[0224] The at least one of the second conduction band setting and the second advance angle setting may gradually increase during the enhanced/second phase P2.

[0225] The at least one of the second conduction band setting and the second advance angle setting increase in steps in accordance with one or more subsequent predetermined time periods (i.e., a stepwise fashion) during the enhanced/second phase P2 (i.e., until the reduction in the load is detected). The at least one of the second conduction band setting and the second advance angle setting increase in steps upon detection of one or more load thresholds on the output spindle. This implementation in which the at least one of the second conduction band setting and the second advance angle setting of the enhanced/second phase P2 may successively increase during the enhanced/second phase P2 is similar to that shown in and described with respect to FIG. 21A.

[0226] The controller 40 is configured to control power delivered to the motor 20, during a third phase of operation after the second phase, upon detection of a reduction of a load on the output spindle. The third phase of operation includes at least one of a third non-zero target rotational speed, a third duty cycle setting, a third conduction band setting, or a third advance angle setting, in order to achieve motor power output during the third phase that is less than the motor power output during the second phase.

[0227] The third phase of operation may interchangeably referred to as phase 3/P3, or as reduced phase of operation. The reduced/third phase P3 may be between the time t2 and time t4 as shown in FIGS. 24A-25B. The reduced/third phase P3 may be between the time t3 and time t4 as shown in FIGS. 24A-25B. The reduced/third phase P3 occurs after the enhanced/second phase P2. The reduced/third phase P3 starts upon detection of a reduction in load on the output spindle. The reduction in the load on the output spindle is shown in FIGS. 24A-25B. In one embodiment, the reduced/third phase P3 may be a closed loop control. In such an embodiment, the reduced/third phase P3 may have the third target rotational speed of 15000 RPM. In such an embodiment, the reduced/third phase P3 may have the third target rotational speed of 12000 RPM. In another embodiment, the reduced/third phase P3 may be an open loop control. In such an embodiment, the reduced/third phase may have the third duty cycle/PWM setting of 50% duty cycle, the third conduction band setting of 120 degrees, or the third advance angle setting of 30 degrees.

[0228] In some situations, at time t2, the fastener may breakaway. This may occur when driving a fastener such as a screw into a workpiece if the head of the fastener breaks or is stripped. This may occur when removing a fastener such as a lug nut when the fastener breaks away from the workpiece. In either case, the motor speed will start to rapidly increase, while the torque rapidly decreases. The controller 40 is configured to sense this event, e.g., by sensing that the speed has exceeded a predetermined motor speed limit, w-limit. At time t3, when the controller 40 senses this event, the power delivered to the motor 20 is rapidly decreased to avoid runaway during the reduced/third period P3 until the trigger 36 is released. During the reduced/third period P3, the tool also reduces the absolute current limit to a third current limit, which may be the same as or different from the first current limit.

[0229] The at least one of the third target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting of the reduced/third phase P3 is less than at least one of the corresponding second target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting of the enhanced/second phase P1.

[0230] The controller 40 may be configured to control power delivered to the motor with at least one of the third non-zero target rotational speed, third duty cycle setting, third conduction band setting or third angle advance setting until the power switch 36 is released by the user. The time at which the power switch 36 is released by the user is shown as trigger release at time t4 in FIGS. 24A-25B.

[0231] The controller 40 may be configured to maintain an amount of current delivered to the motor 20 to be less than or equal to a first current limit, during the baseline/first phase P1, by turning off or reducing power to the motor 20 if the current exceeds the first current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period and then restart power delivery to the motor 20. The controller 40 may be configured to maintain an amount of current delivered to the motor 20 to be less than or equal to a second current limit that is greater than the first current limit, during the enhanced/second phase P2, by turning off or reducing power to the motor 20 if the current exceeds the second current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period and then restart power delivery to the motor 20. The controller 40 may be configured to

maintain an amount of current delivered to the motor 20 to be less than or equal to a third current limit that is less than the second current limit, during the reduced/third phase P3, by turning off or reducing power to the motor 20 if the current exceeds the third current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period and then restart power delivery to the motor 20. The first current limit, the second current limit and the third current limit are shown in FIGS. 24A-25B. That is, during the reduced/third period P3, the tool also reduces the absolute current limit to the third current limit, which may be the same as or different from the first current limit.

[0232] The controller 40 is configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1 using closed loop control, (b) during the enhanced/second phase of operation P2 using open loop control, and (c) during the reduced/ third phase of operation P3 using closed loop control. In another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1 using closed loop control, (b) during the enhanced/second phase of operation P2 using closed loop control, and (c) during the reduced/ third phase of operation P3 using closed loop control. In yet another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1 using open loop control, (b) during the enhanced/second phase of operation P2 using open loop control, and (c) during the reduced/ third phase of operation P3 using open loop control. In another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during baseline/first phase of operation P1, (b) during enhanced/second phase of operation P2, and (c) during the reduced/ third phase of operation P3 using other variations of the open and the closed loop controls.

[0233] In the closed loop control, the controller 40 is configured to set a target motor rotational speed. The controller 40 is configured to maintain the motor speed at the target motor rotational speed by varying the duty cycle/PWM setting, the conduction band setting, and/or the advance angle setting. Examples of target motor speeds (in rpm) for each of the phases of the tenth and the eleventh using closed loop speed control may be as in the TABLE 1 below:

TABLE 1 - Tenth and Eleventh control modes using the closed loop control

Phase	Phase also referred to as	Target Rotational Motor Speed
P1	Baseline Phase	27000 rpm
P2	Enhanced Phase	30000 rpm
P3	Reduced Phase	12000 rpm or 15000 rpm

[0234] In the open loop control, the controller 40 is configured to set a PWM/duty cycle setting, the conduction band setting, and/or the advance angle setting. Generally, baseline PWM is considered 100% duty cycle, baseline conduction band setting is 120 degrees, and baseline advance angle setting is 30 degrees. Enhanced CBAA may be, e.g., 160/50. Reduced PWM may be, e.g., 80% duty cycle or 50% duty cycle. Examples of the duty cycle/PWM setting, the conduction band setting, and/or the advance angle setting for each of the phases of tenth and the eleventh control modes using the open loop control may be as in the TABLE 2 below:

TABLE 2 - Twelfth control mode using the open loop control

Phase	Phase also referred to as	PWM/Duty Cycle Setting	Conduction Band Setting	Advance Angle Setting
P1	Baseline Phase	100% duty cycle	120 degrees	30 degrees
P2	Enhanced Phase	100% duty cycle	160 degrees	50 degrees
P3	Reduced Phase	50% duty cycle	120 degrees	30 degrees

[0235] The closed loop control and the open loop control can be mixed and matched in each of the control modes. For example, in the tenth control mode and the eleventh control mode, the phases P1 and P3 may be closed loop controls, while phase P2 may be an open loop control. Other variations are possible.

[0236] FIG. 26A shows graphical representation of the operation of the motor 20 in one implementation of the twelfth control mode when the controller 40 is selectively operable in a forward mode to drive the motor 20 in a first direction to insert a fastener into a workpiece (i.e., the controller 40 is selectively operable for tightening a fastener into a workpiece). FIG. 26B shows graphical representation of the operation of the motor 20 in another implementation of the twelfth control mode when the controller 40 is selectively operable in a reverse mode to drive the motor 20 in a second, opposite direction to remove a fastener from a workpiece (i.e., when the controller 40 is selectively operable for loosening a fastener from a workpiece).

[0237] FIGS. 26A and 26B each show various motor speed-torque-time curves of the operation of the motor 20 in implementations of the twelfth control mode. The motor speeds (ω) (e.g., measured in RPM) during the operation of the motor 20 in the twelfth mode of operation are shown on the left hand side Y-axes of the graphs in FIGS. 26A and 26B and the torques T (e.g., measured in Nm/s) of the motor 20 during the operation of the motor 20 in the twelfth mode of operation are shown on the right hand side Y-axes of the graphs in FIGS. 26A and 26B, while the time (i.e., measured in seconds) of the operation of the motor 20 in the twelfth mode of operation is shown on the X-axes of the graphs in FIGS. 26A and 26B.

[0238] In implementations of the twelfth control mode as shown in FIGS. 26A and 26B, a first or baseline phase P1 starts upon the trigger 36 actuation and runs until detection of one or more rotational impacts at baseline target rotational speed, baseline PWM/duty cycle setting, baseline conduction band setting and/or baseline advance angle setting, followed by a second or reduced phase P2 with reduced target rotational speed, reduced PWM/duty cycle setting, reduced conduction band setting and/or reduced advance angle setting for a predetermined time period Δt , followed by third or enhanced phase P3 with enhanced target rotational speed, enhanced PWM/duty cycle setting, enhanced conduction band setting or enhanced advance angle setting until the controller 40 detects a reduction in load on the output spindle (e.g., due to fastener stripping, fastener breakage, the impact power tool becoming disengaged from a fastener, or fastener breaking away from workpiece) or a cessation of impacting, followed by a fourth or reduced phase P4 with reduced target rotational speed, reduced PWM/duty cycle setting, reduced conduction band setting and/or reduced advance angle setting.

[0239] In one non-limiting embodiment, one implementation of the twelfth control mode as shown in FIGS. 26A-26B, the first phase P1 includes closed loop control with a baseline target rotational speed, e.g., approximately 27000 rpm, the second phase P2 includes closed loop control with reduced target rotational speed (e.g., a slightly reduced target rotational speed), e.g., approximately 22000 rpm, the third phase P3 comprises open loop control with an enhanced PWM/duty cycle setting (e.g., approximately 100% duty cycle), an enhanced conduction band setting (e.g., approximately 160 degrees) and an enhanced advance angle setting of (e.g., approximately 50 degrees), and P4 includes closed loop control with a reduced target rotational speed (e.g., approximately 15000 rpm).

[0240] In another non-limiting embodiment, the implementations of the twelfth control mode of operation as shown in FIGS. 26A-26B include the first phase P1 with closed loop control with a baseline target rotational speed (e.g., between approximately 25000 rpm and 30000 rpm, such as 27000 rpm), the second phase P2 with closed loop control with reduced target rotational speed (e.g., between approximately 20000 rpm and 25000 rpm, such as 22000 rpm), the third phase P3 with closed loop control with enhanced target rotational speed (e.g., between approximately 30000 rpm and 35000 rpm, such as 30000 rpm), and the fourth phase P4 with closed loop control with reduced target rotational speed (e.g., between approximately 12000 rpm and 18000 rpm, such as 15000 rpm). In yet another non-limiting embodiment, the implementations of the twelfth control mode of operation as shown in FIGS. 26A-26B includes first phase P1 with open loop control with baseline PWM/duty cycle setting (e.g., between approximately 90% and 100% duty cycle), baseline conduction band setting (e.g., approximately 120 degrees) and baseline advance angle setting (e.g., approximately 30 degrees), second phase P2 with open loop control with reduced PWM/duty cycle setting (e.g., approximately 80% to 95% duty cycle, such as 90% duty cycle), a baseline or reduced conduction band setting (e.g., approximately 120 degrees) and a baseline or reduced advance angle setting (e.g., approximately 30 degrees), third phase P3 with open loop control with an enhanced PWM/duty cycle setting (e.g., approximately 100% duty cycle), enhanced conduction band setting (e.g., approximately 120 to 160 degrees, such as 160 degrees), and an enhanced advance angle setting (e.g., approximately 30 to 60 degrees, such as 50 degrees), and fourth phase P4 with open loop control with reduced PWM/duty cycle setting (e.g., approximately 25% to 75% duty cycle, such as 50% duty cycle), a baseline or reduced conduction band setting (e.g., approximately 120 degrees) and a baseline or reduced advance angle setting (e.g., approximately 30 degrees).

[0241] Each of the phases in the implementations of the twelfth control mode as shown in FIGS. 26A and 26B are now explained in detail. The control modes of operation shown in FIGS. 26A and 26B includes the first or baseline phase of operation P1. The controller 40 may be configured to control power delivered to the motor 20, during the baseline phase of operation P1 prior to a reduced/second phase of operation P2, with at least one of the baseline non-zero target rotational speed, the baseline duty cycle setting, the baseline conduction band setting, or the baseline advance angle setting starting when the power switch/trigger 36 is actuated by the user and until the detection of one or more of the rotational impacts.

[0242] The baseline phase of operation may interchangeably referred to as the first phase P1. The baseline phase P1 may be between the time t_0 and time t_1 as shown in FIGS. 26A and 26B. The baseline phase P1 starts upon actuation of the power switch and occurs prior to the second phase P2.

[0243] In this control mode (which are the same in forward and reverse), at time t_0 , the trigger 36 is actuated and the controller 40 is configured to set a first relatively high target motor rotational speed ω_1 , a baseline conduction band setting of 120 degrees and a baseline advance angle setting of 30 degrees, and to control the motor using closed loop control. When tightening a fastener (as shown in FIG. 26A), the actual speed rapidly ramps up to the target motor

rotational speed, while the torque on the fastener increases. The actual speed is maintained close to the target motor rotational speed, with possibly some decline until time t_1 , when impacting of the impact power tool is detected. When loosening a fastener, as shown in Fig. 26B, the actual motor speed rapidly ramps up toward the target motor rotational speed, prior to the tool beginning to impact at time t_1 . The target motor rotational speed may not be achieved prior to the tool beginning to impact.

[0244] Referring to FIGS. 26A-26B, the controller 40 is configured to control power delivered to the motor 20, during the second phase P2 of operation for a predetermined time period Δt starting after detection of one or more of the rotational impacts at time t_1 and until time t_2 . The second phase P2 of operation may have one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting.

[0245] The second phase P2 of operation may interchangeably referred to as a reduced phase of operation. The predetermined time period Δt may be factory set or adjustably set by the user. The detection of one or more of the rotational impacts are shown at time t_1 (as impact detected) in FIGS. 26A-26B. The detection of one or more of the rotational impacts are described in detail in earlier embodiments in this patent application and, hence, will not be described again here.

[0246] The reduced or second phase P2 may comprise closed loop control having the second non-zero rotational target speed, the second conduction band setting, and the second advance angle setting, with a variable second duty cycle. In one embodiment, the second phase P2 may comprise closed loop control with a fixed the second target rotational speed (e.g., approximately 22000 rpm), a fixed conduction band setting (e.g., approximately 120 degrees), a fixed advance angle setting (e.g., approximately 30 degrees), and a variable duty cycle. In another embodiment, the second phase P2 may comprise open loop control with a fixed second duty cycle setting that is reduce (e.g., approximately 90% duty cycle), a fixed second conduction band setting (e.g., approximately 120 degrees), a fixed second advance angle setting (e.g., approximately 30 degrees), and a variable motor speed.

[0247] At least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting of the reduced/second phase P2 may be less than at least one of the corresponding baseline non-zero target rotational speed, baseline duty cycle setting, baseline conduction band setting, or baseline advance angle setting of the baseline/first phase P1. For example, the second non-zero target rotational speed of the reduced/second phase P2 (e.g., approximately 22000 RPM) may be less than baseline non-zero target rotational speed of the baseline/first phase P1 (e.g., approximately 27000 RPM). The second duty cycle of the reduced/second phase P2 (e.g., approximately 90% duty cycle) may be less than the corresponding baseline duty cycle of the baseline phase P1 (e.g., approximately 100% duty cycle). At least one of the corresponding second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting of the second phase P2 may achieve a second power output that is less than the first power output during the first phase P1.

[0248] During reduced/second phase P2, as the torque on the fastener increases and tool continues to impact, the controller 40 may be unable to maintain the target speed, and the actual motor speed may decrease as torque increases. During the baseline/first phase P1 and the reduced/second phase P2, the controller has an absolute first current limit; if current exceeds the first current limit, the tool will shut down or current will be reduced, at least temporarily.

[0249] The controller 40 is configured to control power delivered to the motor, during the third phase P3 of operation after the second phase P2 of operation, starting upon expiration of the predetermined time period Δt . The third phase P3 of operation has one or more of a third non-zero target rotational speed, a third duty cycle setting, or a third advance angle setting, in order to achieve motor power output during the third phase P3 that is greater than motor power output during the second phase P2. The motor power output during the third phase P3 also may be greater than the motor power output during the first phase P1.

[0250] The third phase P3 of operation may interchangeably referred to as an enhanced phase of operation (i.e., enhanced phase). The enhanced/third phase P3 starts upon expiration of the predetermined time Δt at time t_2 and continues until the controller detects a load reduction or that impacting has stopped at time t_3 . The enhanced/third phase P3 occurs after the second/reduced phase P2. Exemplary embodiments of detecting a reduction in the load on the output spindle or cessation of impacting are described below with respect to FIGS. 27A-27B.

[0251] At time t_2 , upon expiration of the time period Δt , the controller 40 provides for enhanced power to the motor 20 by increasing one or more of duty cycle (e.g., to approximately 100%, if not already there), conduction band setting (e.g., to approximately 160 degrees) and/or advance angle setting (e.g., to approximately 50 degrees). This change provides a boost in current and power delivered to the motor. This may be performed using open loop control with, e.g., 100% duty cycle; however, the controller 40 could execute closed loop control. In either type of control, the output speed of the motor 20 may tend to increase at the start of enhanced/third period P3 and then decrease as torque continues to increase. Because the third phase P3 requires greater current, the absolute current limit may be increase temporarily to a second current limit.

[0252] The third phase P3 of operation may comprise open loop control having the third duty cycle setting, the third conduction band setting, and the third advance angle setting, with a variable second rotational speed. In such an

embodiment, the enhanced/third phase P3 may have a third duty cycle setting of 100% duty cycle, a third conduction band setting of 160 degrees, and/or a third advance angle setting of 50 degrees. In another embodiment, the enhanced/third phase P3 may comprise closed open loop control with a higher third target rotational speed than during the first phase (e.g., approximately 28000 to 35000 rpm, such as 30000 rpm).

[0253] In the implementations of twelfth control mode of operation in FIGS. 26A-26B, at least one of the third non-zero target rotational speed, third duty cycle setting, third conduction band setting, and/or third advance angle setting of the enhanced/third phase P3 may be greater than at least one of the corresponding first non-zero target rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting of the baseline/first phase P1 and/or at least one of the corresponding second non-zero target rotational speed, second duty cycle setting, second conduction band setting, and/or second advance angle setting of the reduced/second phase P2. For example, the second non-zero target rotational speed of the enhanced/third phase P3 may be 30000 RPM, which is greater than the corresponding first non-zero target rotational speed of the baseline/first phase P1 of 27000 RPM and is greater than the corresponding second non-zero target rotational speed of the reduced/second phase P2 of 22000 RPM.

[0254] During the enhanced/third phase P3, the at least one of the third conduction band setting and the third advance angle setting of the enhanced/third phase P3 may be greater than the at least one of the first conduction band setting and the first advance angle setting of the baseline/first phase P1 and/or greater than at least one of the second conduction band setting and the second advance angle setting of the reduced/second phase P2. For example, the third conduction band setting of the enhanced/third phase P3 of 160 degrees is greater than the first conduction band setting of the baseline/first phase P1 of 120 degrees and is greater than the second conduction band setting of the reduced/second phase P2 of 120 degrees. For example, the third advance angle setting of the enhanced/third phase P3 is greater than the first advance angle setting of the baseline/first phase P1 of 30 degrees and is greater than the second advance angle setting of the reduced/second phase P2 of 30 degrees.

[0255] During the enhanced/third phase P3, the at least one of the third conduction band setting and the third advance angle setting of the enhanced/third phase P3 may successively increase during the enhanced/third phase P3. For example, in enhanced/third phase P3 and in a forward enhanced mode, the controller 40 may be configured to control the motor 20 with a third conduction band value and a third advance angle value for a third predetermined time period. After the third predetermined time period and in the forward enhanced mode, the controller 40 may be configured to control the motor 20 with one or more subsequent conduction band values and one or more subsequent advance angle values during one or more subsequent predetermined time periods. During each subsequent predetermined time period, at least one of the subsequent conduction band value may be greater than the conduction band value during the immediately preceding predetermined time period or the subsequent advance angle value may be greater than the advance angle value during the immediately preceding predetermined time period.

[0256] At least one of the third conduction band setting and the third advance angle setting may gradually increase during the enhanced/third phase P3.

[0257] At least one of the third conduction band setting and the third advance angle setting increase in steps in accordance with one or more subsequent predetermined time periods (i.e., a stepwise fashion) during the enhanced/third phase P3 (i.e., until the reduction in the load is detected). At least one of the third conduction band setting and the third advance angle setting increase in steps upon detection of one or more load thresholds on the output spindle. This implementation in which the at least one of the third conduction band setting and the third advance angle setting of the enhanced/third phase P3 may successively increase during the enhanced/third phase P3 is similar to that shown in and described with respect to FIG. 21A.

[0258] The controller 40 is configured to control power delivered to the motor 20, during a fourth phase P4 of operation after the third phase of operation P3 upon detection of a reduction in load on the output spindle or detection that the impact power tool has stopped impacting. The fourth phase P4 of operation has one or more of a fourth non-zero target rotational speed, a fourth duty cycle setting, a fourth conduction band setting, or a fourth advance angle setting, in order to achieve motor power output during the fourth phase that is less than the motor power output during the third phase P3.

[0259] The fourth phase of operation may interchangeably referred to as phase 4/P4, or as second reduced phase of operation (i.e., second reduced phase). The reduced/fourth phase P4 may be between the time t4 and time t5 as shown in FIGS. 26A and 26B. The reduced/fourth phase P4 may be between the time t3 and time t5 as shown in FIGS. 26A and 26B. The reduced/fourth phase P4 occurs after the enhanced/third phase. The reduced/fourth phase P4 starts upon detection of a reduction in load on the output spindle. The reduction in the load on the output spindle is shown in FIGS. 26A and 26B. In one embodiment, the reduced/fourth phase P4 may be closed loop control. In such an embodiment, the reduced/fourth phase may have the fourth target rotational speed of 15000 RPM. In such an embodiment, the reduced/fourth phase may have the fourth target rotational speed of 12000 RPM. In another embodiment, the reduced/fourth phase may be open loop control. In such an embodiment, the reduced/fourth phase may have the fourth duty cycle setting of 50% duty cycle, the fourth conduction band setting of 120 degrees, or the fourth advance angle setting of 30 degrees.

[0260] At least one of the fourth target rotational speed, fourth duty cycle setting, fourth conduction band setting, or

fourth advance angle setting of the reduced/fourth phase P4 may be less than at least one more of the corresponding target rotational speeds, duty cycle settings, conduction band settings, and/or advance angle settings of the first, second, and/or third phases P1, P2, and/or P3.

[0261] In some situations, at time t_3 , the fastener may breakaway. This may occur when driving a fastener such as a screw into a workpiece if the head of the fastener breaks or is stripped. This may occur when removing a fastener such as a lug nut when the fastener breaks away from the workpiece. In either case, the motor speed will start to rapidly increase, while the torque rapidly decreases. The controller 40 is configured to sense this event, e.g., by sensing that the speed has exceeded a predetermined motor speed limit, w -limit. At time t_4 , when the controller senses this event, the power delivered to the motor is rapidly decreased to avoid runaway during the second reduced/fourth period P4 until the trigger 36 is released.

[0262] During the second reduced/fourth period P4, the tool also reduces the current limit to a third current limit, which may be the same as or different from the first current limit.

[0263] The controller 40 may be configured to control power delivered to the motor 20 with the at least one of the fourth non-zero target rotational speed, fourth duty cycle setting, fourth conduction band setting or fourth advance angle setting of the reduced/fourth phase P4 until the power switch 36 is released by the user. The time at which the power switch 36 is released by the user is shown as trigger release at time t_5 in FIGS. 26A and 26B.

[0264] The controller 40 may be configured to maintain an amount of current delivered to the motor 20 to be less than or equal to a first current limit (as shown in FIGS. 26A and 26B), during the baseline/first phase P1 and the second phase P2, by turning off or reducing power to the motor 20 if the current exceeds the first current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period then restart power delivery to the motor 20.

[0265] The controller 40 may be configured to maintain an amount of current delivered to the motor 20 to be less than or equal to a second current limit (as shown in FIGS. 26A and 26B) that is greater than the first current limit, during the enhanced/third phase P3, by turning off or reducing power to the motor 20 if the current exceeds the second current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period then restart power delivery to the motor 20.

[0266] The controller 40 may be configured to maintain an amount of current delivered to the motor 20 to be less than or equal to a third current limit (as shown in FIGS. 26A and 26B) that is less than the second current limit, during the reduced/fourth phase P4, by turning off or reducing power to the motor 20 if the current exceeds the third current limit. In some implementations, the controller 40 may turn off or reduce power for a predetermined time period then restart power delivery to the motor 20. The first current limit, the second current limit, and the third current limit are shown in FIGS. 26A-26B.

[0267] The controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1 using closed loop control, (b) during the reduced/second phase of operation P2 using closed loop control, (c) during the enhanced/third phase of operation P3 using open loop control, and (d) during the reduced/fourth phase of operation P4 using closed loop control. In another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1, (b) during the reduced/second phase of operation P2, (c) during the enhanced/third phase of operation P3, and (d) during the reduced/fourth phase of operation P4 all using closed loop control. In yet another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1, (b) during the reduced/second phase of operation P2, (c) during the enhanced/third phase of operation P3, and (d) during the reduced/fourth phase of operation P4 all using open loop control. In another embodiment, the controller 40 may be configured to control power delivered to the motor 20 (a) during the baseline/first phase of operation P1, (b) during the reduced/second phase of operation P2, (c) during the enhanced/third phase of operation P3, and (d) during the reduced/fourth phase of operation P4 using other variations of the open and the closed loop controls.

[0268] In the closed loop control, the controller 40 is configured to set a target motor rotational speed. The controller 40 is configured to maintain the motor speed at the target motor rotational speed by varying the duty cycle/PWM setting, the conduction band setting, and/or the advance angle setting. Examples of target motor speeds (in rpm) for each of the phases of the twelfth control mode using closed loop speed control may be as in the TABLE 3 below:

TABLE 3 - Twelfth control mode using the closed loop control

Phase	Phase also referred to as	Target Rotational Motor Speed
P1	Baseline Phase	27000 rpm
P2	Reduced Phase	22000 rpm
P3	Enhanced Phase	30000 rpm

(continued)

Phase	Phase also referred to as	Target Rotational Motor Speed
P4	Second Reduced Phase	12000 rpm or 15000 rpm

[0269] In the open loop control, the controller 40 is configured to set a PWM/duty cycle setting, the conduction band setting, and/or the advance angle setting. Generally, baseline PWM is considered 100% duty cycle, baseline conduction band setting is 120 degrees, and baseline advance angle setting is 30 degrees. Enhanced conduction band and advance angle setting may be, e.g., 160/50. Reduced PWM may be, e.g., 80% duty cycle or 50% duty cycle. Examples of the duty cycle/PWM setting, the conduction band setting, and/or the advance angle setting for each of the phases of the twelfth control modes using the open loop control may be as in the TABLE 4 below:

TABLE 4 - Twelfth control mode using the open loop control

Phase	Phase also referred to as	PWM/Duty Cycle Setting	Conduction Band Setting	Advance Angle Setting
P1	Baseline Phase	100% duty cycle	120 degrees	30 degrees
P2	Reduced Phase	90% duty cycle	120 degrees	30 degrees
P3	Enhanced Phase	100% duty cycle	160 degrees	50 degrees
P4	Second Reduced Phase	50% duty cycle	120 degrees	30 degrees

[0270] The closed loop control and the open loop control can be mixed and matched in each of the control modes. For example, in the twelfth control mode, the phases P1 and P2 may comprise closed loop control, phase P3 may comprise open loop control, and phase P4 may comprise closed loop control. Other variations are possible.

[0271] FIGS. 27A and 27B show various motor speed-time curves of the operation of the motor 20. The motor speeds (ω) (e.g., measured in RPM) during its operation are shown on the left hand side Y-axes of the graphs in FIGS. 27A and 27B, while the time (i.e., measured in seconds) of the operation of the motor 20 is shown on the X-axes of the graphs in FIGS. 26A and 26B.

[0272] In the embodiments of FIGS. 24A-26B, the controller is configured to sense a reduction of load on the output spindle or a cessation of impacting (e.g., due to fastener breakaway), e.g., by sensing when the motor speed exceeds a predetermined speed value. In other embodiments, a reduction of load or a cessation of impacting may be detected by a sound sensor that senses a noise signature of impacting, by an output torque transducer or sensor to detect a rapid drop in torque on the output spindle, a current sensor to detect a drop in output torque of the motor, and/or a vibration sensor to detect cessation of impacts. FIGS. 27A and 27B illustrate additional techniques for sensing reduction of load or a cessation of impacting. For example, an increase in rotational velocity of motor or an increase in rotational acceleration of motor may be sensed to detect cessation of impacting or to detect a reduction in load. Sensing an increase in rotational velocity of motor or sensing an increase in rotational acceleration of motor may be performed either in an analog manner or in a digital manner.

[0273] The sensing feature (i.e., sensing an increase in rotational velocity of motor or sensing an increase in rotational acceleration of motor) may be implemented in an impact power tool that comprises a housing; a brushless motor received in the housing; a controller configured to control power delivery to the motor in response to actuation of a power switch; an impact mechanism configured to be driven by the motor; an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle; and a sensor configured to sense a speed of the motor. The impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold. The features of these components of the impact power tool have been described in the patent application and, hence, will not be described in detail here again.

[0274] The controller of the impact power tool is configured to determine that a load on the output shaft has been reduced and decrease power delivered to the motor when at least one of: (a) the sensed motor speed exceeds a threshold value for a predetermined number of sample cycles, (b) the sensed motor speed is increasing for a predetermined number of sample cycles, or (c) an acceleration of the motor is increasing for a predetermined number of sample cycles. The threshold value may be predetermined. The reduction in the load on the output shaft may be due to breaking of head of the fastener, due to stripping of the threads of the fastener, etc.

[0275] As shown in FIG. 27A, generally during impacting of the impact power tool, the motor speed varies with each consecutive peak and trough indicating an impact. The controller may sample the motor speed at a regular time based sampling frequency, as indicated in FIG. 27A (e.g., 60 samples per second). In this embodiment, the controller samples

the speed and stores in memory the lowest speed sensed by storing the first speed sensed and then storing in memory a new minimum speed every time that a lower speed is detected. This lowest speed stored at any given time is referred to as a global minimum value of speed. As illustrated in the example of FIG. 27A, the global minimum speed is reset four times (indicated by the first, the second, the third and the fourth global minimum speed). At each sample interval, the sensed motor speed also computes the difference $\Delta\omega$ between the sensed speed to the latest stored global minimum speed by calculating the difference. FIG. 27A illustrates representative difference calculations for speed differences that are sensed at the time at or close to the peaks of the speed curve, as indicated by speed differences $\Delta\omega_1, \Delta\omega_2, \Delta\omega_3, \Delta\omega_4, \Delta\omega_5, \Delta\omega_6, \Delta\omega_7, \Delta\omega_8, \Delta\omega_9$, and $\Delta\omega_{10}$.

[0276] In another embodiment, the controller is configured to continuously monitor the motor speed to obtain the lowest speed that may be stored as a local minimum speed (i.e., vs. global minimum speed). In such an embodiment, at each sample interval, the sensed motor speed also computes the difference $\Delta\omega$ between the sensed speed to the stored local minimum speed by calculating the difference.

[0277] The controller may determine that the load has been reduced or that impacting has ceased when the controller determines that a differences between the sensed motor speed during impacting and during a specific phase is increasing for a predetermined number of sample cycles or that the speed difference $\Delta\omega$ is greater than a predetermined threshold amount for a predetermined number of sample cycles. For example, the lowest sensed motor speed during impacting and during a specific phase is the lowest sensed motor speed during impacting and is shown as global minimum value in FIG. 27A. As can be seen in FIG. 27A, the differences between the lowest global minimum speed and the sampled motor speed is increasing for a predetermined number of sample cycles (i.e., for the sample cycles indicated by $\Delta\omega_7, \Delta\omega_8, \Delta\omega_9$ and $\Delta\omega_{10}$ in FIG. 27A, which indicates a reduction in load or cessation in impacting (e.g., due to fastener breakaway). The reduction or cessation in impacting could alternatively be determined by the magnitude of the difference of one or more of these samples being greater than a threshold value, e.g., one or more of $\Delta\omega_7, \Delta\omega_8, \Delta\omega_9$ and $\Delta\omega_{10}$ are greater than a threshold speed difference.

[0278] The controller may be configured to detect fastener breakaway (or the reduction in the load on the output shaft) by sensing an increase in the difference of the current motor speed versus the global minimum. The controller may be configured to sense the difference $\Delta\omega$ between the current speed and the global minimum for each sample cycle exceeding a predetermined threshold for one or more sample cycles or sense that the difference $\Delta\omega$ between the peak and the trough for each impact cycle is increasing (e.g., that the motor is accelerating or that the acceleration is increasing).

[0279] The controller may determine that the sensed motor speed is increasing by receiving a signal from the sensor that indicates whether the motor speed exceeds a threshold motor speed and determining that the signal indicates that the motor speed exceeds the threshold motor speed for a predetermined number of consecutive sample cycles. The threshold motor speed may also be referred to as motor speed threshold. In one embodiment, the threshold motor speed may be calculated as stated above. In another embodiment, the threshold motor speed may be predetermined.

[0280] As shown in FIG. 27B, in another embodiment, the sensed motor speed signal may be passed through a filter (e.g., a low pass filter) that generates a filtered motor speed signal that may be, e.g., a moving average of the sensed motor speed signal. As shown in the example of FIG. 26A, the filtered motor speed signal is a smoothed signal that may roughly correspond to an average speed of the motor without the peaks and troughs. At regular sample intervals, the sensed motor speed is compared to the filtered motor speed signal. The sensed motor speed is shown as speed signal in FIG. 27B and the filtered motor speed signal is shown as filtered signal in FIG. 27B. For example, a difference between the actual/sensed motor speed signal and the filtered motor speed signal is taken (i.e., (actual/sensed motor speed signal - filtered motor speed signal)). In one embodiment, the filtered motor speed signal is the motor speed threshold. In another embodiment, the filtered motor speed signal includes a predetermined static motor speed threshold.

[0281] In an example, the controller may generate an output of 0 when the sensed motor speed is less than a filtered motor speed signal and an output of 1 when the sensed motor speed is greater than the filtered motor speed signal. FIG. 27B illustrates the outputs of 0s and 1s that are generated in response to the sensed motor speeds as compared to the filtered motor speed signal during impacting operation of the impact power tool. In an alternative embodiment, the sensed motor speed may be compared to a predetermined speed threshold instead of or in addition to a filtered motor speed signal to determine whether the sensed speed is above or below the threshold.

[0282] As can be seen from FIG. 27B, during normal impacting operation of the impact power tool, the output from the output tends to generally vary between the outputs of 1s and the outputs of 0s (i.e., between single or small numbers of sample cycles) as the motor speed fluctuates upon repeated impacts.

[0283] Upon reduction in the load on the output shaft or cessation of impacting (e.g., due to fastener breakaway, the motor speed rapidly increases, and the outputs of the digital filter tends to be only having the outputs of 1s. If the controller detects that the number of consecutive outputs of 1s exceeds a threshold (e.g., predetermined) amount, the controller then determines that reduction in load or cessation of impacts has occurred and decreases the power to the motor (e.g., during the phase 3 of the tenth and eleventh control mode or the phase 4 of the twelfth control mode). Referring to FIG. 27B, the controller detects that five consecutive outputs of 1s before determining that the load on the output shaft or cessation of impacts has occurred and the power to the motor is reduced.

[0284] The controller 40 may be configured to control power delivered to the motor 20 prior to determining that a load on the motor 20 has been reduced by controlling current delivered to the motor 20 based on one or more of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting. The controller may be configured to control power delivered to the motor 20 after determining that a load on the motor 20 has been reduced by controlling current delivered to the motor 20 based on one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting. The determination that a load on the output spindle has been reduced may correspond to cessation of impacting.

[0285] The impact power tool may include an indicator for when the impact power tool is operating in one of the control modes discussed in the patent application. For example, the impact power tool may have an indicator to indicate to the user that impact power tool is in the portion of the control mode with enhanced parameters (i.e., one or more of the non-zero target rotational speed, the duty cycle/PWM setting, the conduction band setting and/or the advance angle setting). This indicator feature may apply to any of the eighth control mode (as shown in FIGS. 21-22B), the ninth control mode (as shown in FIGS. 23A-23B), the tenth control mode (as shown in FIGS. 24A-24B), the eleventh control mode (as shown in FIGS. 25A-25B), or the twelfth control mode (as shown in FIGS. 26A-26B). For example, the indicator may be a visual indicator to indicate to the user that impact power tool is in the portion of the control mode with enhanced parameters. The visual indicator may include an illuminating light emitting diode (LED), a flashing LED, a color changing LED, a brightness changing LED, an LED that turns ON or OFF, or other visual indicators. The impact power tool may also have an audio or sound indicator. The impact power tool may be a speaker that plays a sound to indicate to the user that impact power tool is in the portion of the control mode with enhanced parameters. The impact power tool may also have a servo motor that vibrates to indicate to the user that impact power tool is in the portion of the control mode with enhanced parameters.

[0286] Although the terms first, second, third, etc. may be used herein to describe various modes, (predetermined) time periods, conduction band values, advance angle values, etc., these modes, time periods, conduction band values, advance angle values should not be limited by these terms. These terms may be only used to distinguish one mode, time period, conduction band value, advance angle value from another mode, time period, conduction band value, advance angle value. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first mode, a first time period, a first conduction band value, a first advance angle value discussed above could be termed a second mode, a second time period, a second conduction band value, and a second advance angle value, respectively without departing from the teachings of the example embodiments.

[0287] The impact tool 10 may have greater or fewer number of modes than those described above.

[0288] The values/ranges noted above detailed description are exemplary. In one embodiment, the values/ranges are up to 10 percent greater than or up to 10 percent less than the value described above. In another example embodiment, the values/ranges are up to 5 percent greater than or up to 5 percent less than the value described above.

[0289] Example embodiments have been provided so that this disclosure will be thorough, and to fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail. For example, Further, any of the aforementioned modes may be used during forward and/or reverse operation of the motor and may be used for installing or removing fasteners as desired by the user.

[0290] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0291] When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0292] Terms of degree such as "generally," "substantially," "approximately," and "about" may be used herein when

describing the relative positions, sizes, dimensions, or values of various elements, components, regions, layers and/or sections. These terms mean that such relative positions, sizes, dimensions, or values are within the defined range or comparison (e.g., equal or close to equal) with sufficient precision as would be understood by one of ordinary skill in the art in the context of the various elements, components, regions, layers and/or sections being described.

[0293] Numerous modifications may be made to the exemplary implementations described above. These and other implementations are within the scope of this application.

Claims

1. An impact power tool comprising:

a housing;
 a brushless motor received in the housing;
 a power switch configured to be actuated by a user;
 a controller operatively connected with the motor and configured to control power delivery to the motor in response to actuation of the power switch;
 an impact mechanism configured to be driven by the motor; and
 an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle, the impact mechanism configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold,
 wherein the controller is configured to control power delivered to the motor during a first phase of operation starting upon actuation of the power switch,
 wherein the controller is configured to control power delivered to the motor, during a second phase of operation for a predetermined time period after detection of one or more of the rotational impacts, the second phase of operation having one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting,
 wherein the controller is configured to control power delivered to the motor, during a third phase of operation after the second phase of operation and starting upon expiration of the predetermined time period, the third phase of operation having one or more of a third non-zero target rotational speed, a third duty cycle setting, a third conduction band setting, or a third advance angle setting, in order to achieve motor power output during the third phase that is greater than motor power output during the second phase, and
 wherein the controller is configured to control power delivered to the motor, during a fourth phase of operation after the third phase of operation upon detection of a reduction in load on the output spindle or cessation of impacting, the fourth phase of operation having one or more of a fourth non-zero target rotational speed, a fourth duty cycle setting, a fourth conduction band setting, or a fourth advance angle setting, in order to achieve motor power output during the fourth phase that is less than the motor power output during the third phase.

2. The impact power tool of claim 1, wherein at least one of the third non-zero target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting is greater than at least one of the corresponding second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting.

3. The impact power tool of claim 1, wherein the second phase of operation comprises closed loop control having the second non-zero rotational target speed, the second conduction band setting, and the second advance angle setting, with a variable second duty cycle wherein, preferably, the third phase of operation comprises open loop control having the third duty cycle setting, the third conduction band setting, and the third advance angle setting, with a variable third rotational speed.

4. The impact power tool of claim 1, wherein at least one of the fourth target rotational speed, fourth duty cycle setting, fourth conduction band setting, or fourth advance angle setting is less than at least one of the corresponding third target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting.

5. The impact power tool of claim 1, wherein the controller is configured to control power delivered to the motor during the first phase of operation with at least one of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting starting when the power switch is actuated by a user and until the detection of one or more of the rotational impacts, wherein, preferably, at least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle

setting is less than at least one of the corresponding first non-zero target rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting, wherein, preferably, the at least one of the corresponding first non-zero target rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting achieves a first power output that is greater than the second power output.

5 6. The impact power tool of claim 1, wherein the second conduction band setting and the second angle advance value setting are constant during the second phase.

10 7. The impact power tool of claim 6, wherein, the at least one of the third conduction band setting and the third advance angle setting are greater than the at least one of the second conduction band setting and the second advance angle setting and successively increase during the third phase.

15 8. The impact power tool of claim 5, wherein the controller is configured to maintain an amount of current delivered to the motor to be less than or equal to a first current limit, during the first phase and the second phase, by turning off or reducing power to the motor if the current exceeds the first current limit,

wherein the controller is configured to maintain an amount of current delivered to the motor to be less than or equal to a second current limit that is greater than the first current limit, during the third phase, by turning off or reducing power to the motor if the current exceeds the second current limit, and

20 wherein the controller is configured to turn off or reduce power to the motor for a time period if one of the current limits is exceeded and then restart power delivery to the motor after the time period.

9. An impact power tool comprising:

25 a housing;

a brushless motor received in the housing;

a power switch configured to be actuated by a user;

a controller operatively connected with the motor and configured to control power delivery to the motor in response to actuation of the power switch;

30 an impact mechanism configured to be driven by the motor; and

an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle, the impact mechanism configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold,

35 wherein the controller is configured to control power delivered to the motor, during a first phase of operation, for a predetermined time period or until detection of one or more of the rotational impacts, the first phase of operation having one or more of a first non-zero target rotational speed, a first duty cycle setting, a first conduction band setting, or a first advance angle setting,

40 wherein the controller is configured to control power delivered to the motor, during a second phase of operation after the first phase and starting upon expiration of the predetermined time period or detection of one or more of the rotational impacts, the second phase of operation having one or more of a second non-zero target rotational speed, a second duty cycle setting, a second conduction band setting, or a second advance angle setting, in order to achieve motor power output during the second phase that is greater than motor power output during the first phase, and

45 wherein the controller is configured to control power delivered to the motor, during a third phase of operation after the second phase, upon detection of a reduction of a load on the output spindle, the third phase of operation having at least one of a third non-zero target rotational speed, a third duty cycle setting, a third conduction band setting, or a third advance angle setting, in order to achieve motor power output during the third phase that is less than the motor power output during the second phase.

50 10. The impact power tool of claim 9, wherein at least one of the second non-zero target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting is greater than at least one of the corresponding first non-zero rotational speed, first duty cycle setting, first conduction band setting, or first advance angle setting.

55 11. The impact power tool of claim 9, wherein at least one of the third target rotational speed, third duty cycle setting, third conduction band setting, or third advance angle setting is less than at least one of the corresponding second target rotational speed, second duty cycle setting, second conduction band setting, or second advance angle setting.

12. The impact power tool of claim 9, wherein the first conduction band setting and the first angle advance setting are constant during the first phase, wherein, preferably, during the second phase, the at least one of the second conduction band setting and the second advance angle setting are greater than the at least one of the first conduction band setting and the first advance angle setting and successively increase during the second phase.

13. The impact power tool of claim 9, wherein the controller is configured to maintain an amount of current delivered to the motor to be less than or equal to a first current limit, during the first phase, by turning off or reducing power to the motor if the current exceeds the first current limit,

wherein the controller is configured to maintain an amount of current delivered to the motor to be less than or equal to a second current limit that is greater than the first current limit, during the second phase, by turning off or reducing power to the motor if the current exceeds the second current limit, and wherein the controller is configured to turn off or reduce power to the motor for a time period if one of the current limits is exceeded and then restart power delivery to the motor after the time period.

14. The impact power tool comprising:

a housing;

a brushless motor received in the housing;

a controller configured to control power delivery to the motor in response to actuation of a power switch;

an impact mechanism configured to be driven by the motor;

an output spindle configured to receive rotational impacts from the impact mechanism to rotate the output spindle; and

a sensor configured to sense a speed of the motor,

wherein the impact mechanism is configured to selectively apply the rotational impacts to the output spindle when a torque on the output spindle exceeds a threshold, and

wherein the controller is configured to determine that a load on the output spindle has been reduced and decrease power delivered to the motor when at least one of: (a) the sensed motor speed exceeds a threshold value for a predetermined number of sample cycles, (b) the sensed motor speed is increasing for a predetermined number of sample cycles, or (c) an acceleration of the motor is increasing for a predetermined number of sample cycles.

15. The impact power tool of claim 14, wherein the controller determines that the sensed motor speed is increasing when the controller determines that a difference between a lowest sensed motor speed and the sensed motor speed is increasing for a predetermined number of sample cycles wherein the controller determines that the sensed motor speed is increasing by receiving a signal from the sensor that indicates whether the motor speed exceeds a threshold motor speed and determining that the signal indicates that the motor speed exceeds the threshold motor speed for a predetermined number of consecutive sample cycles.

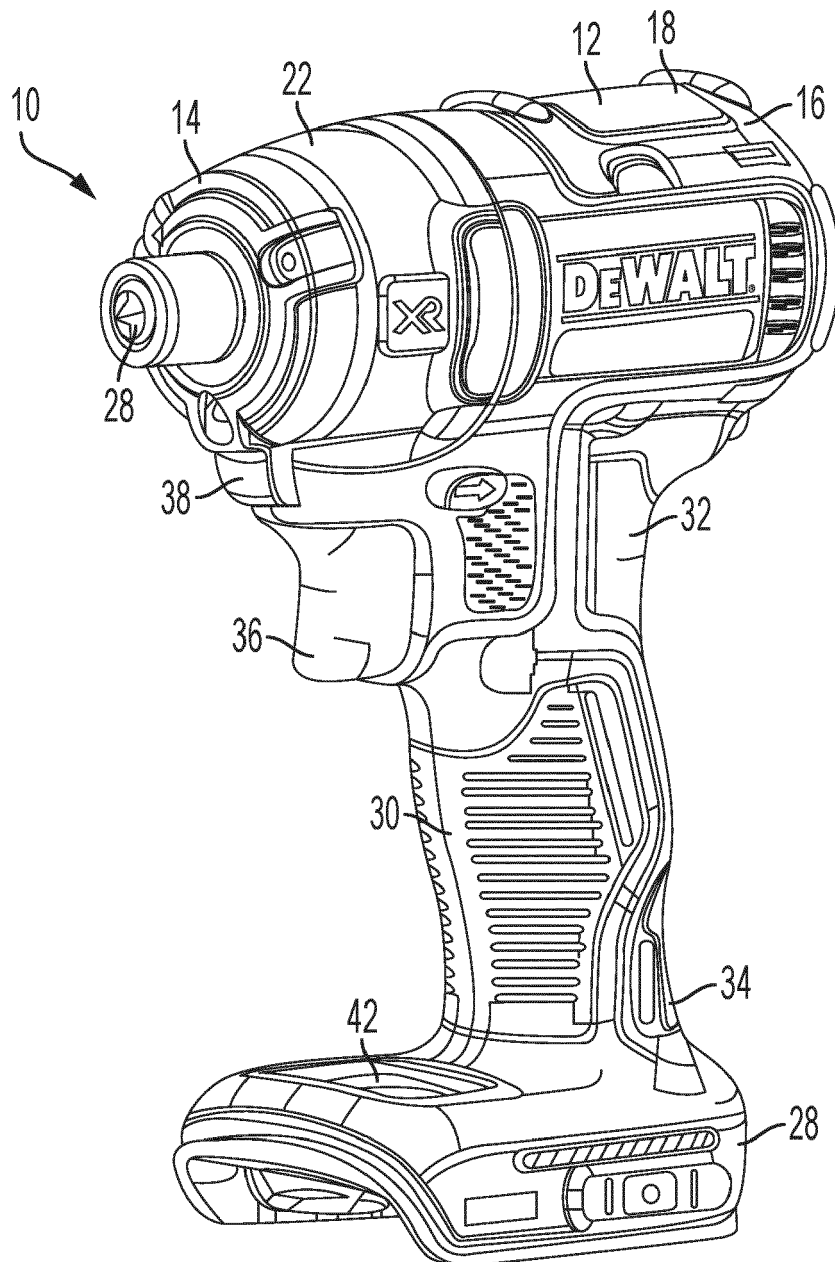


FIG. 1

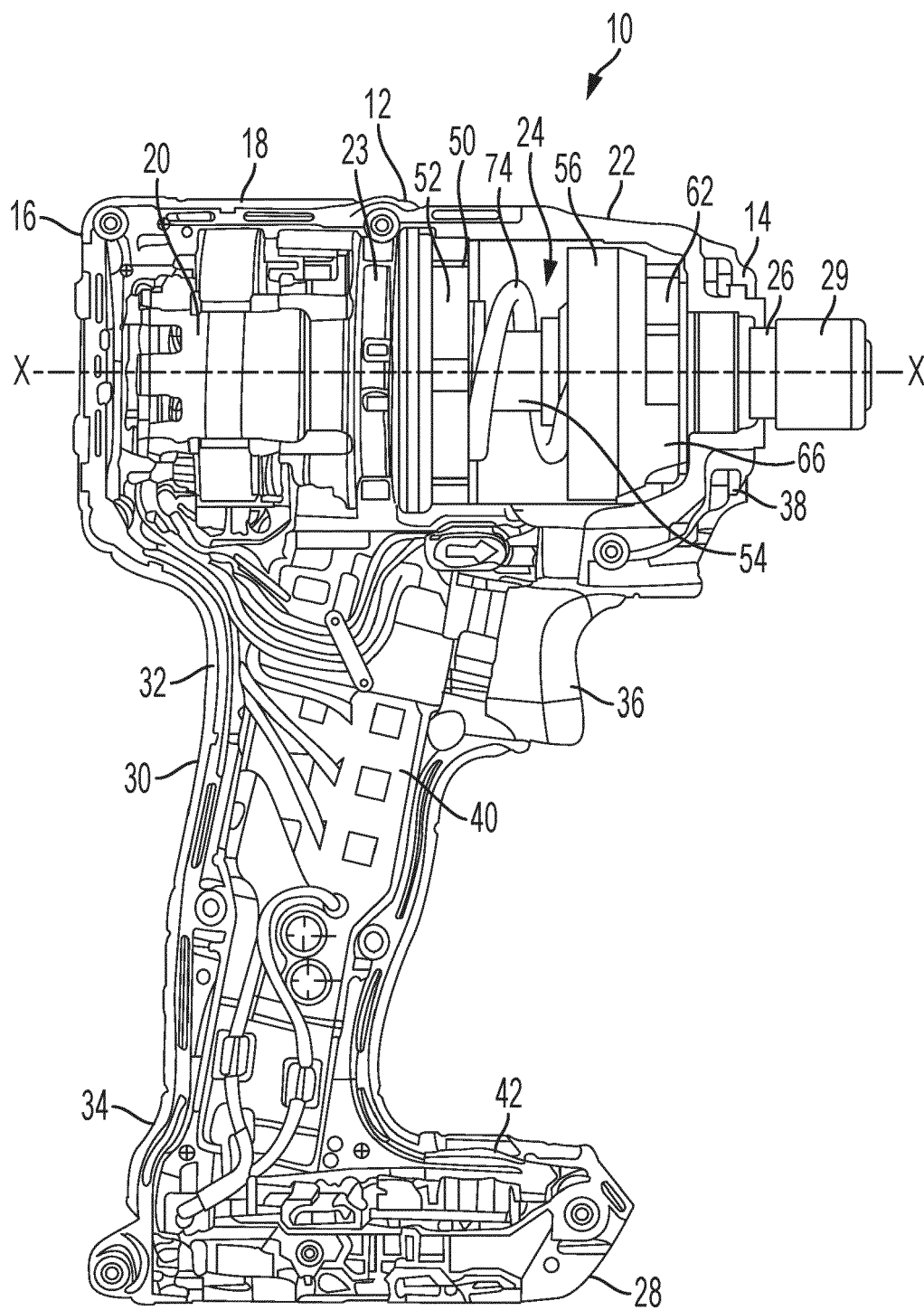
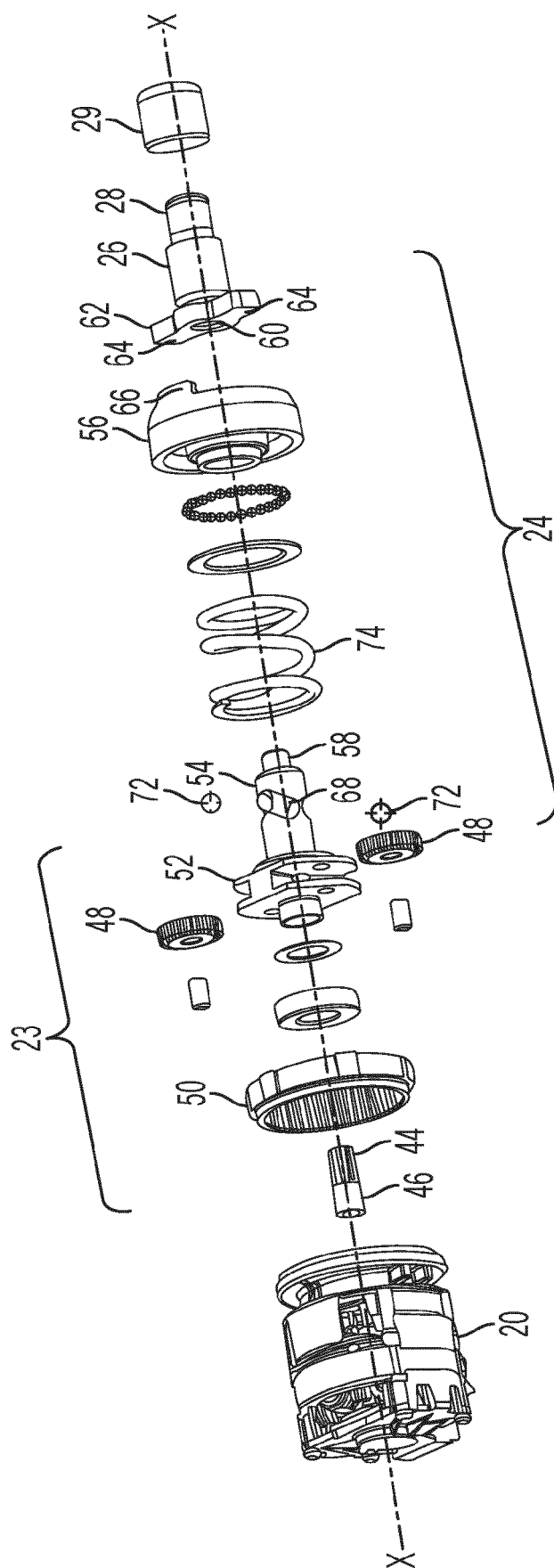


FIG. 2



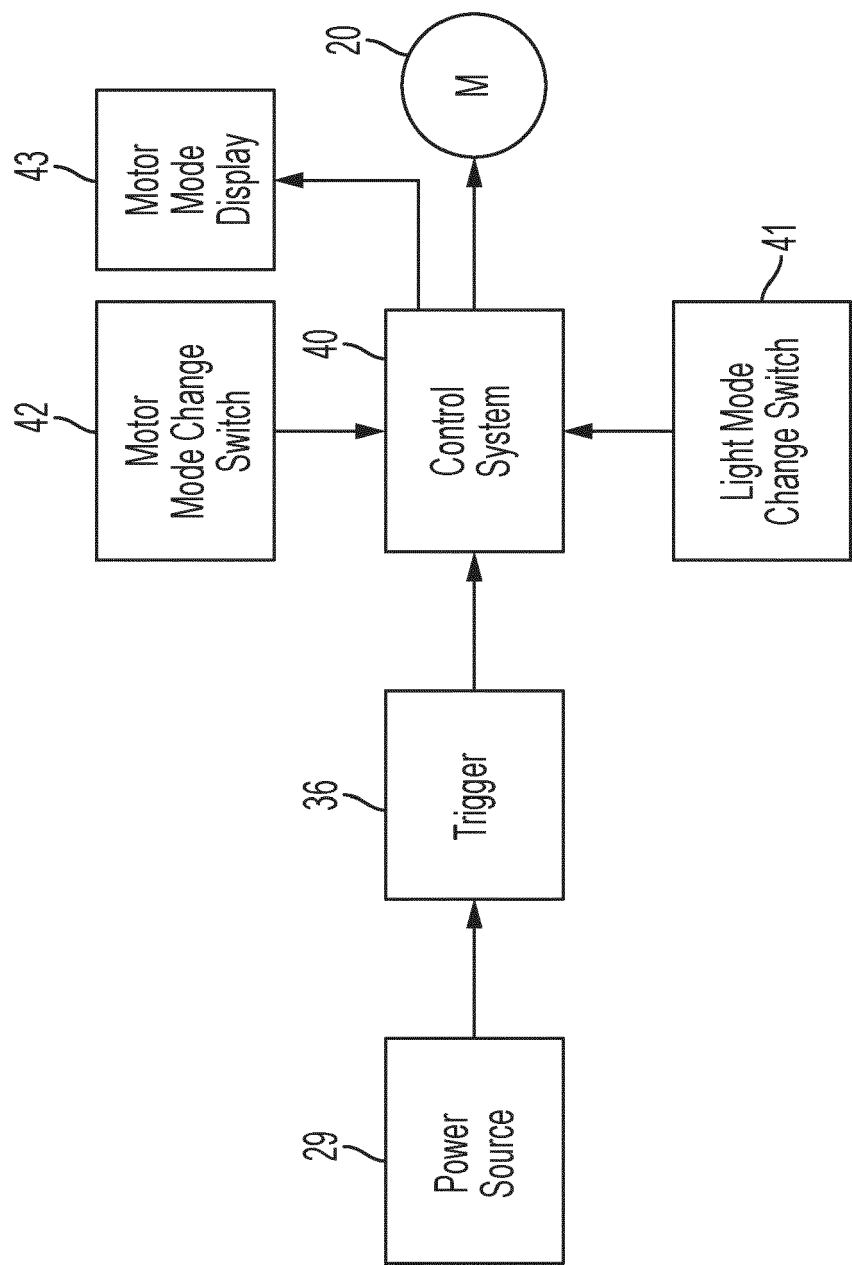


FIG. 4

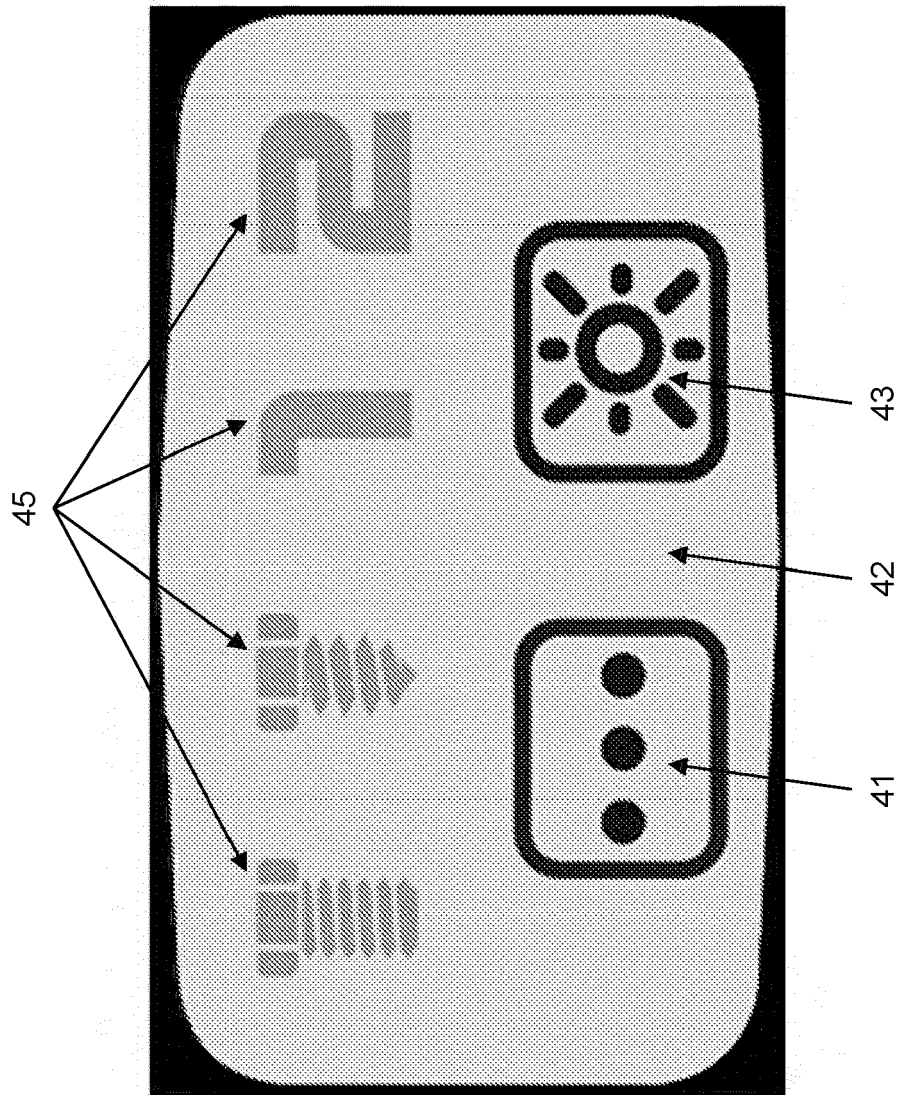


FIG. 5

Control Mode 1 (High Speed)

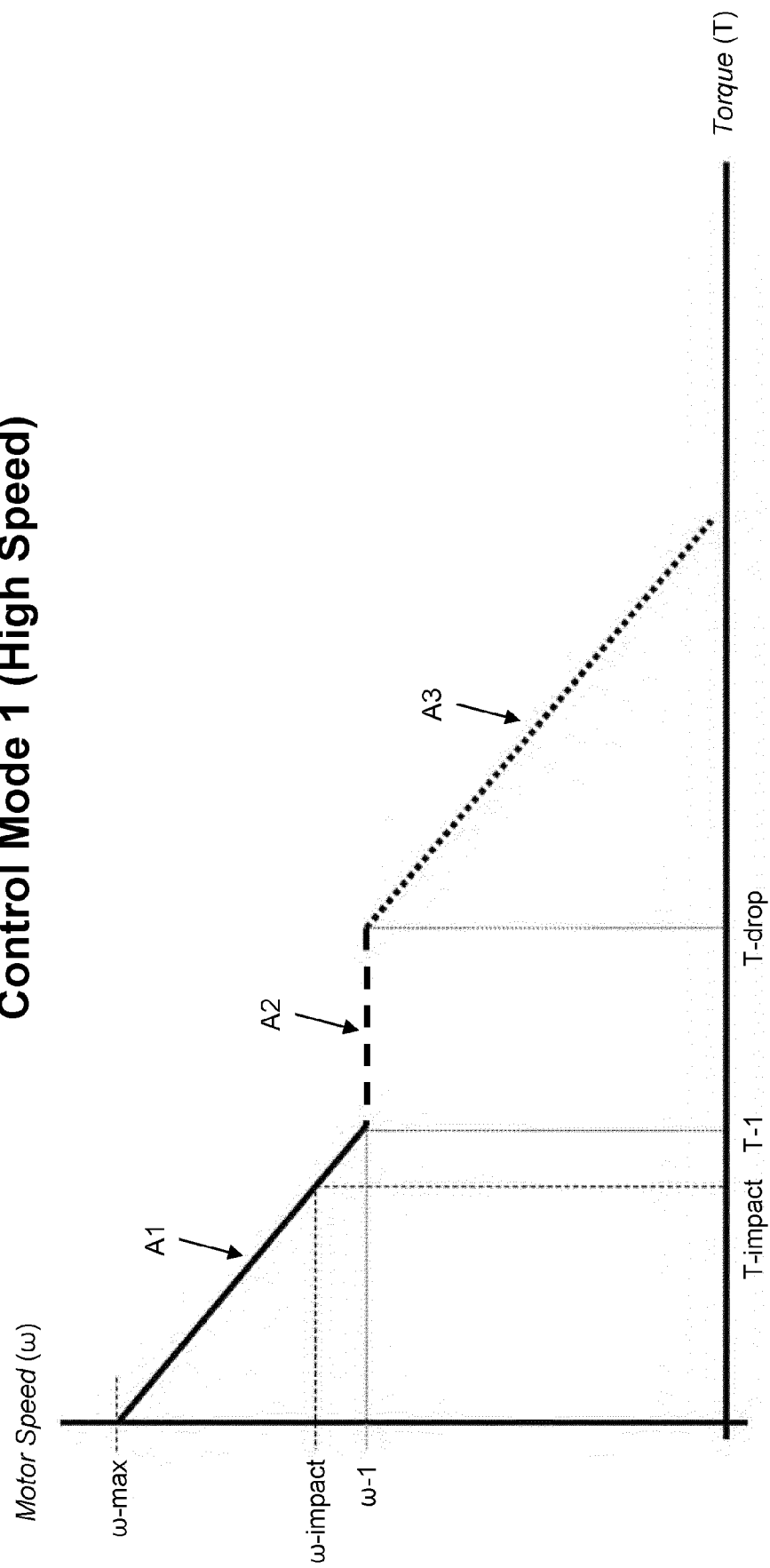


FIG. 6

Control Mode 2 (Low Speed)

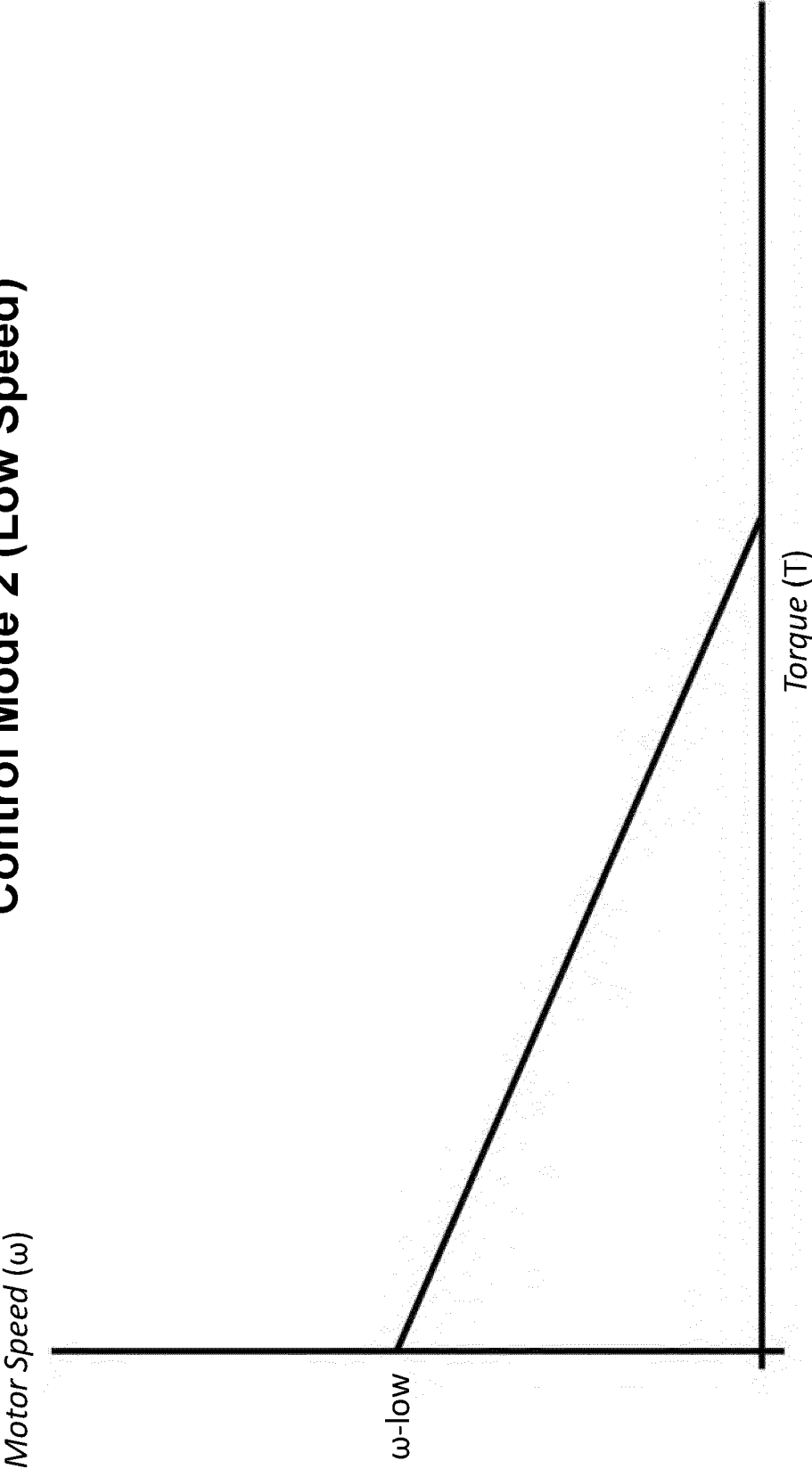


FIG. 7

Control Mode 3 (Soft Joint)

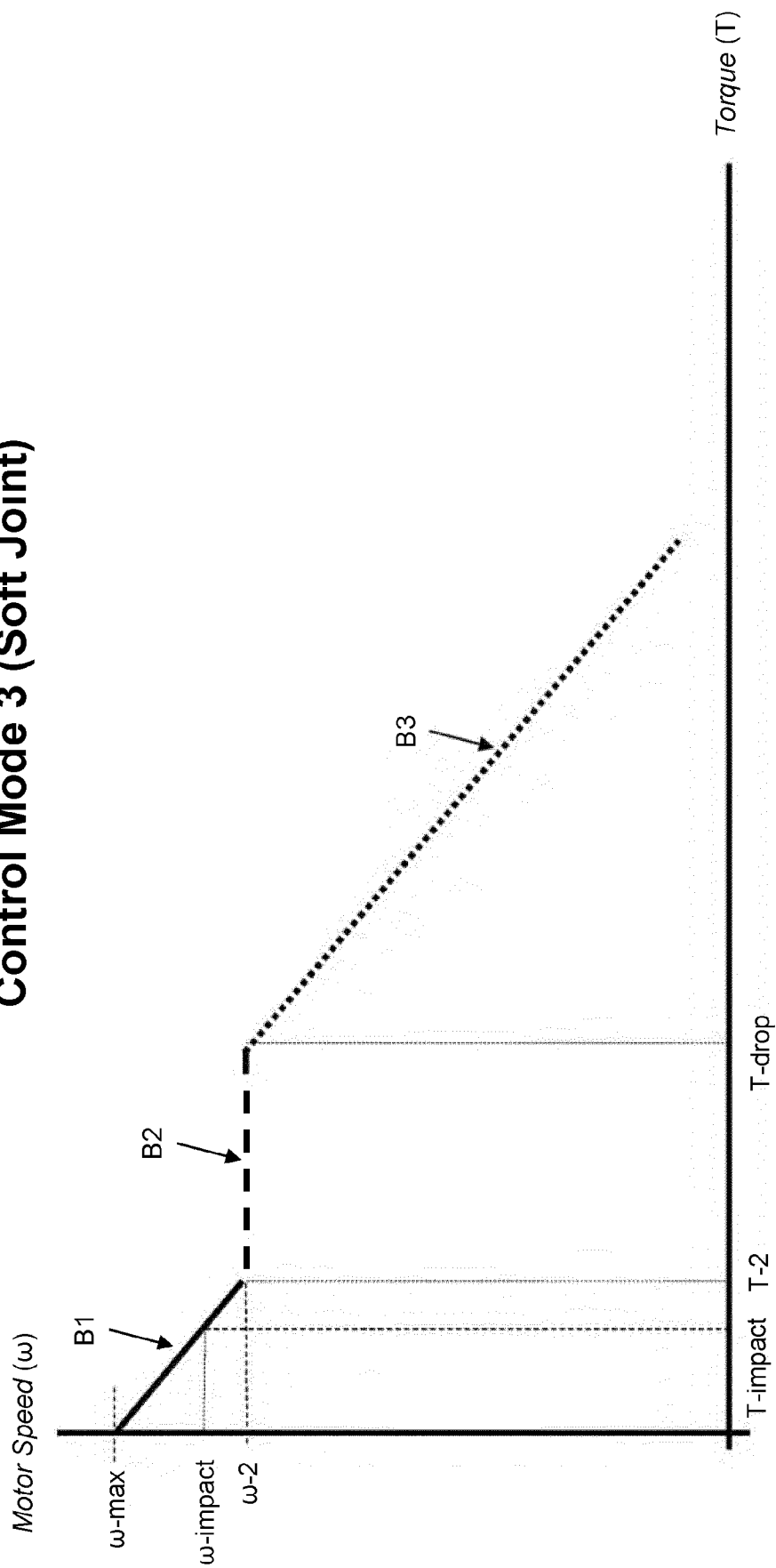


FIG. 8

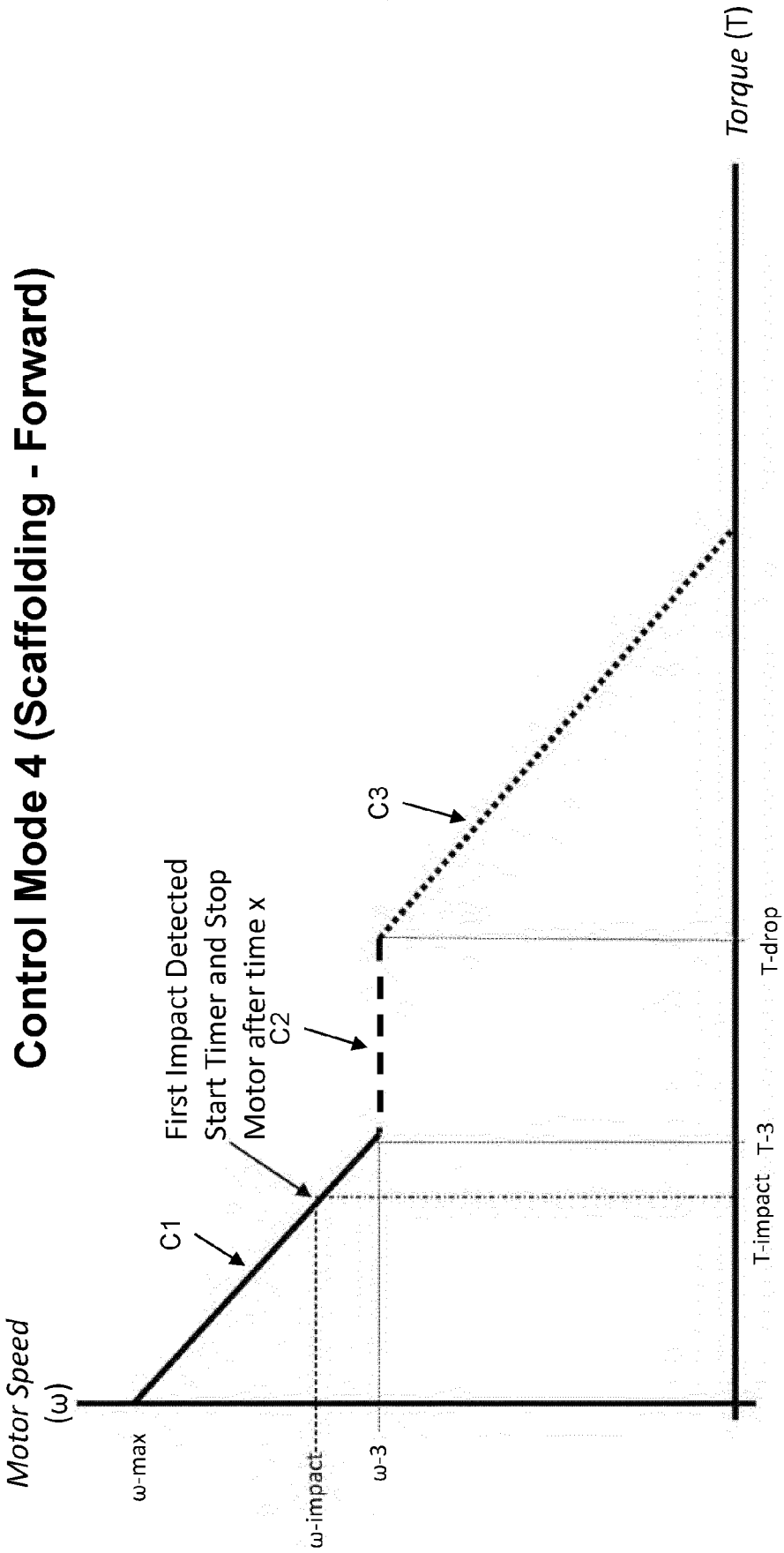


FIG. 9

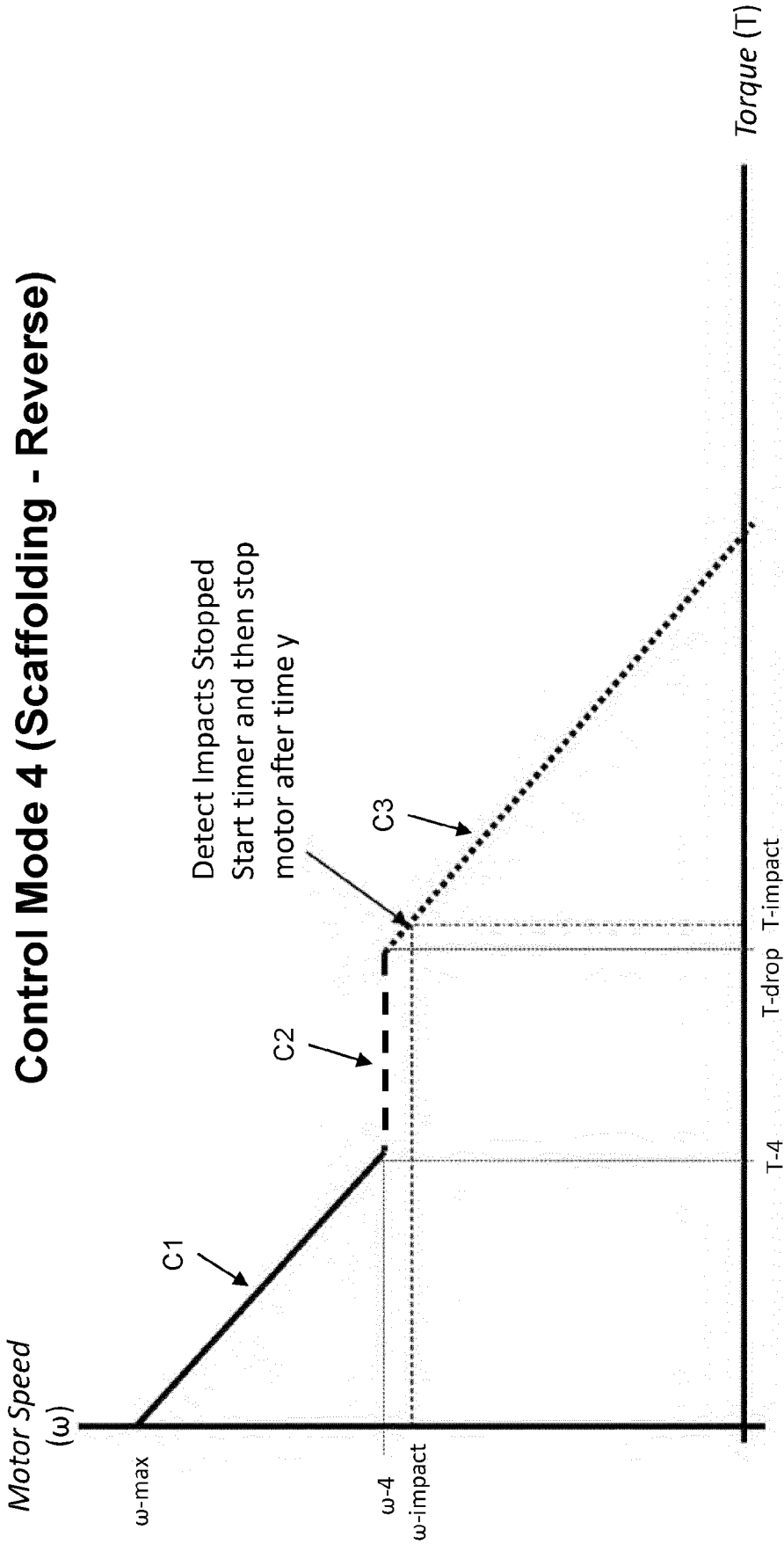


FIG. 10

Control Mode 5 (Installation Precision Mode)

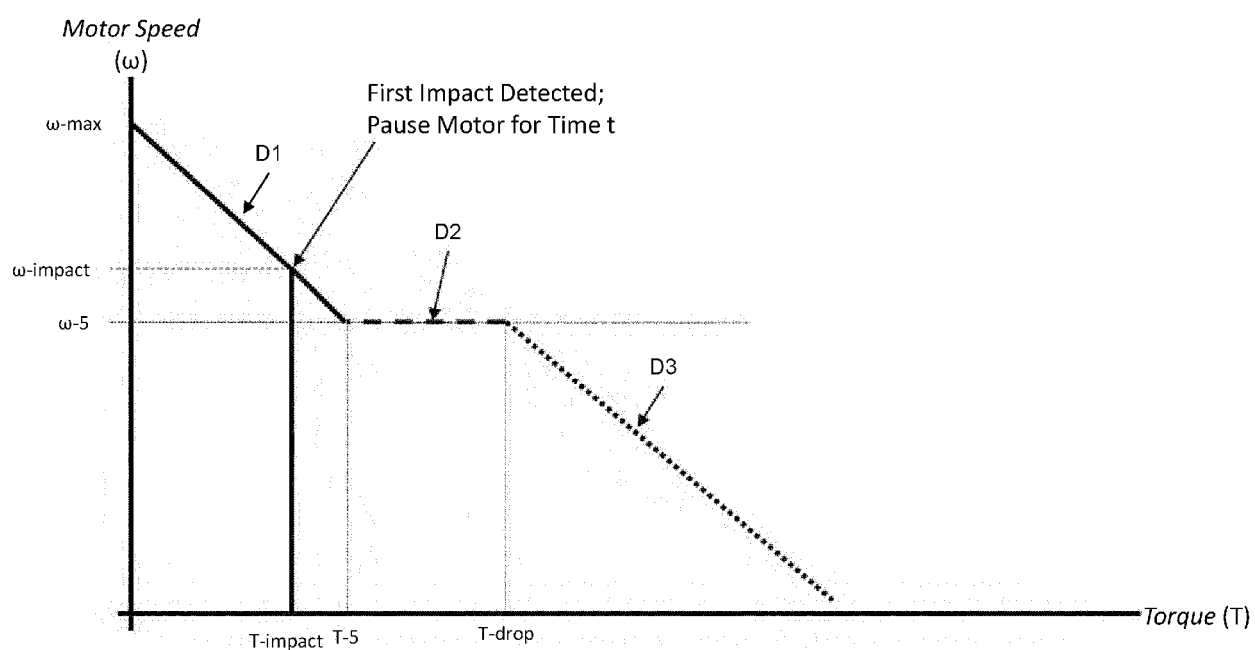


FIG. 11

Control Mode 5 (Removal Precision Mode)

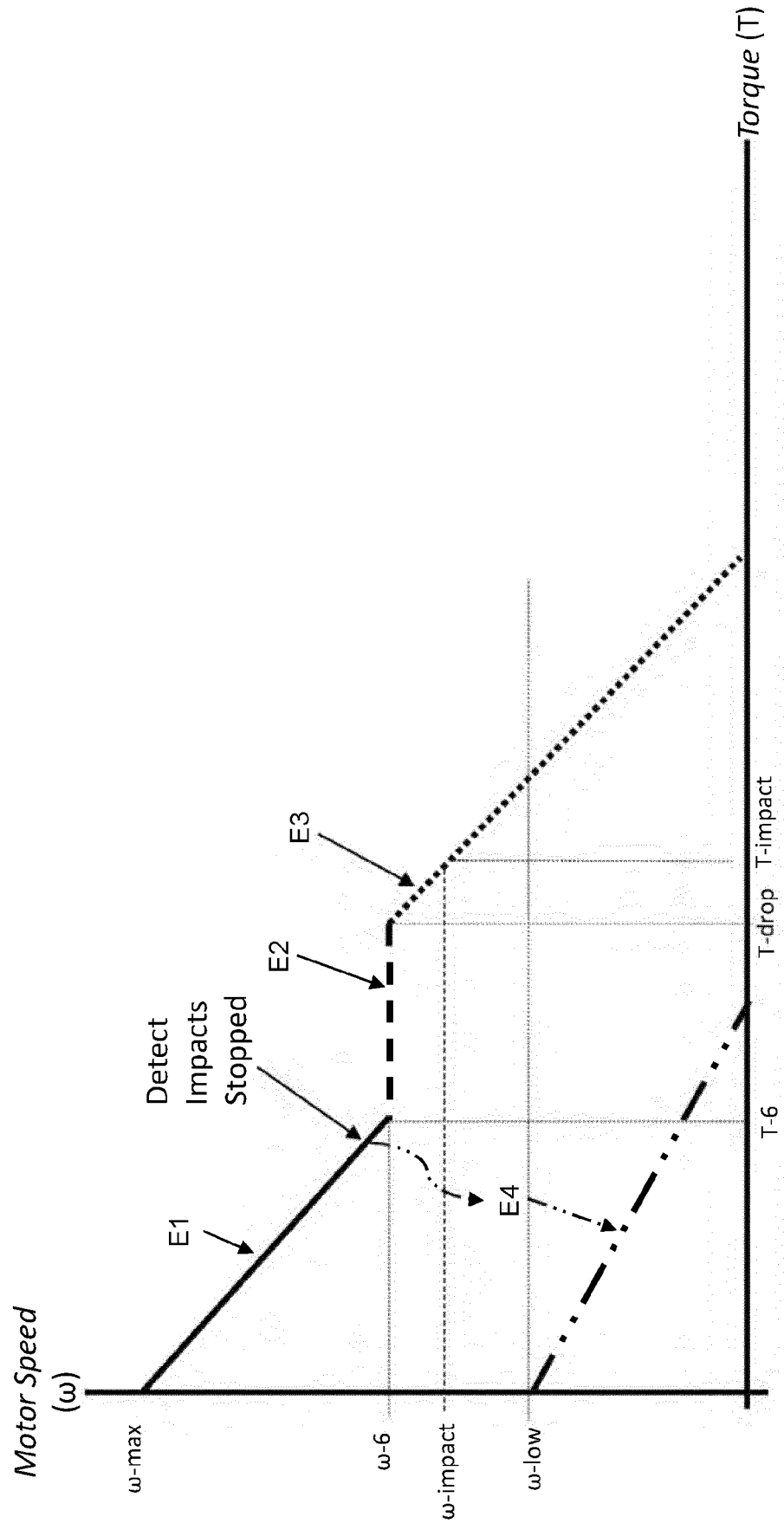


FIG. 12

Control Mode 6 (Quiet Mode)

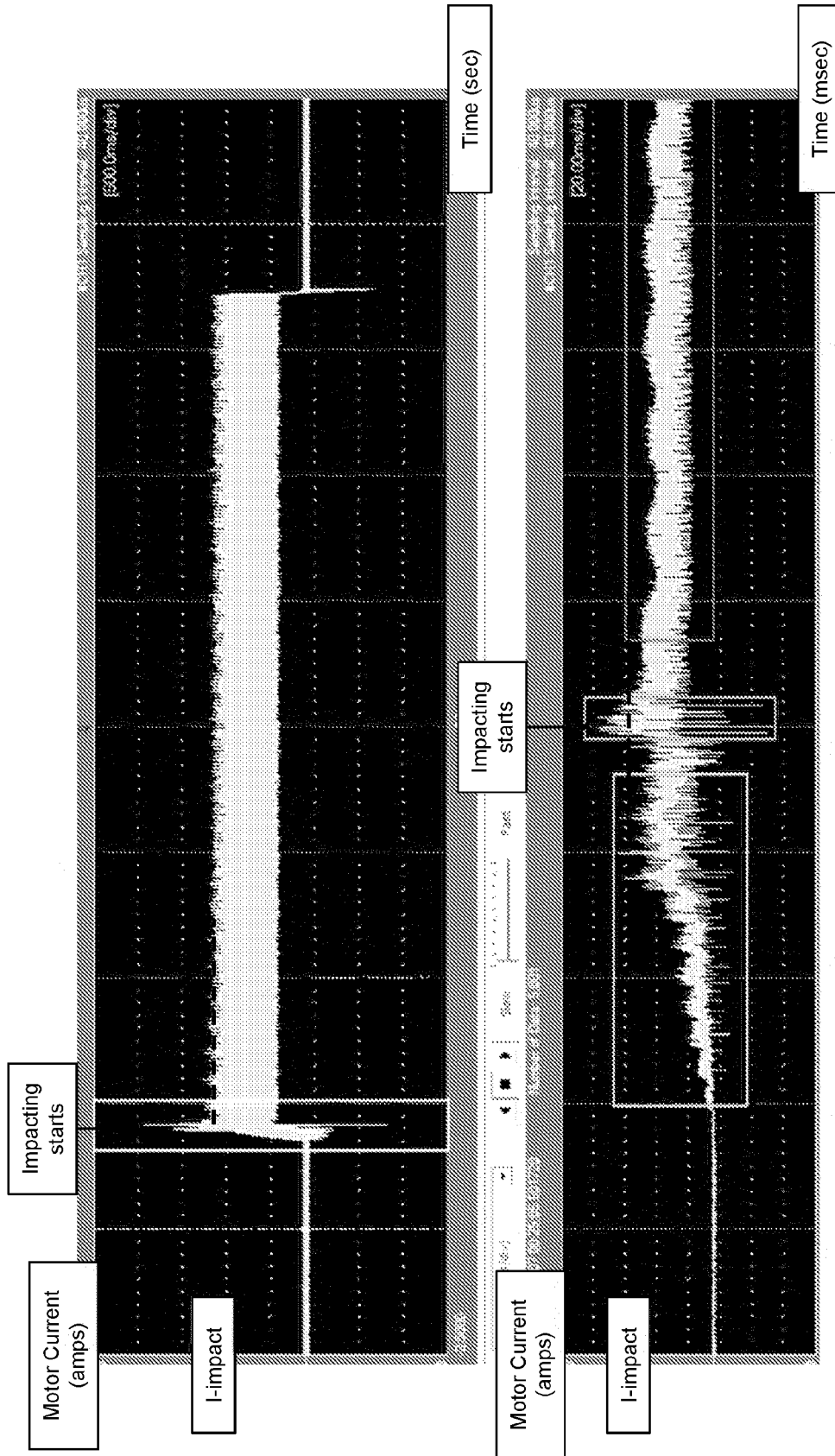


FIG. 13

Control Mode 6 (Quiet Mode)

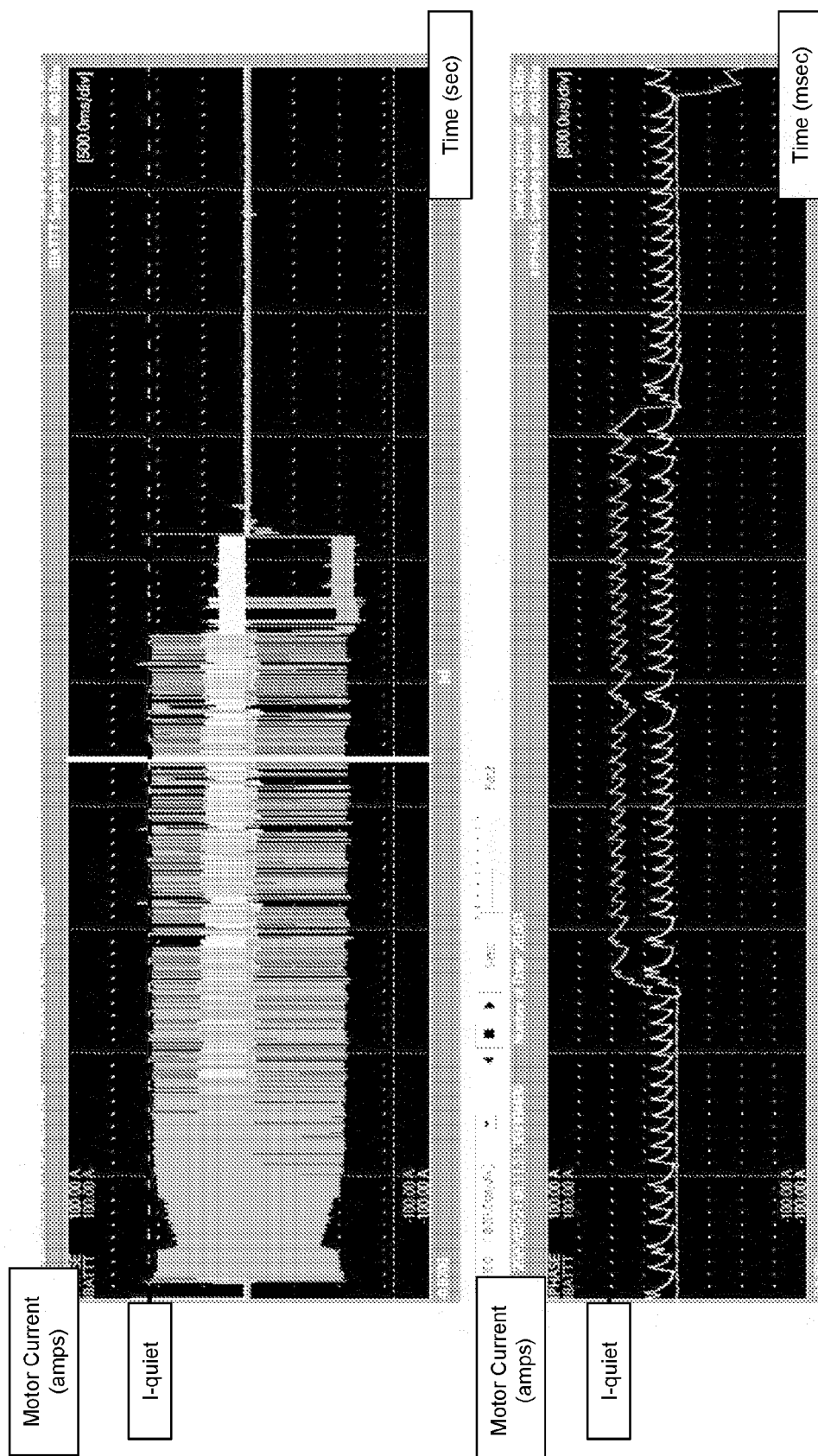


FIG. 14

Control Mode 7 (Protection Mode)

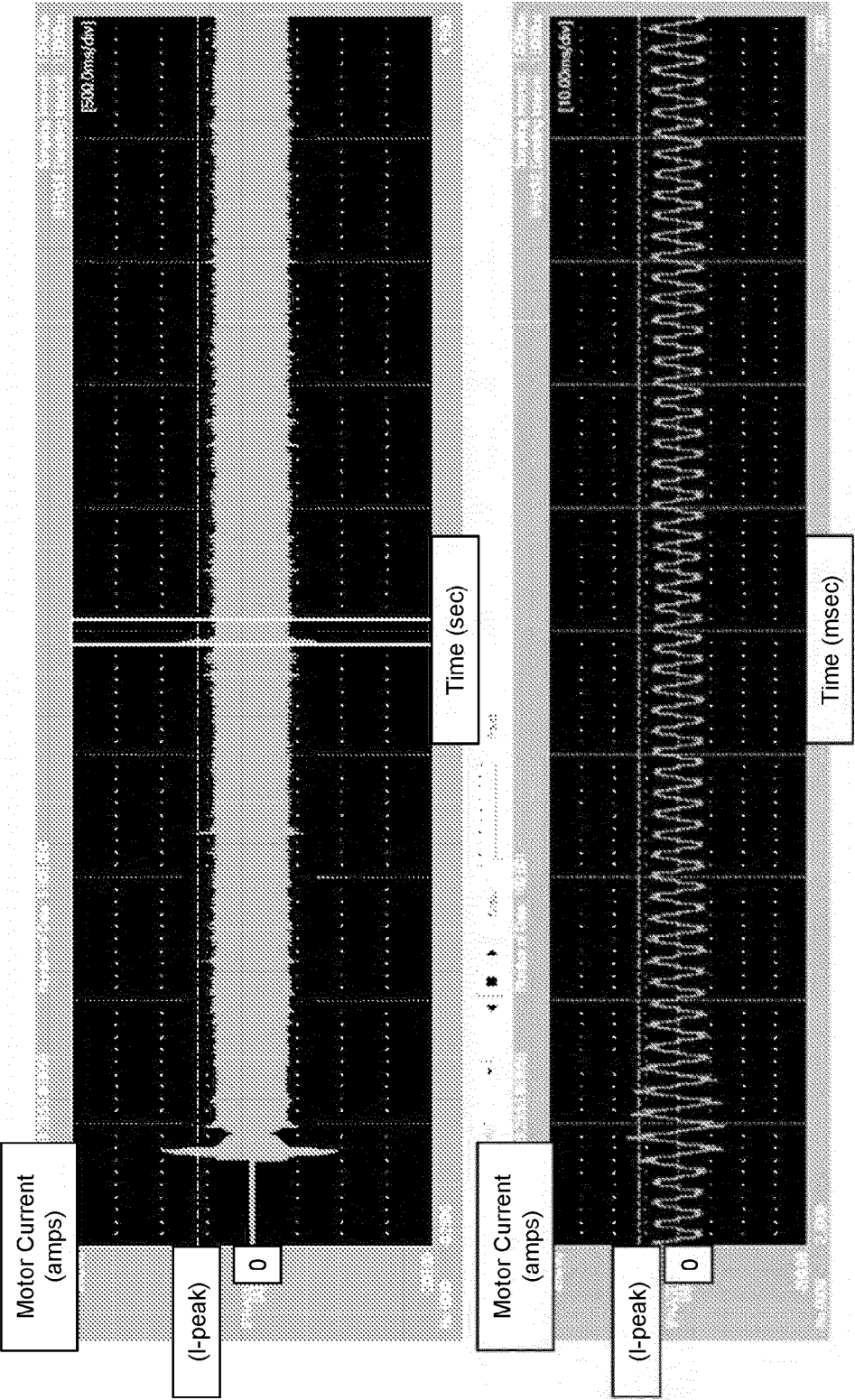


FIG. 15

Control Mode 7 (Protection Mode)

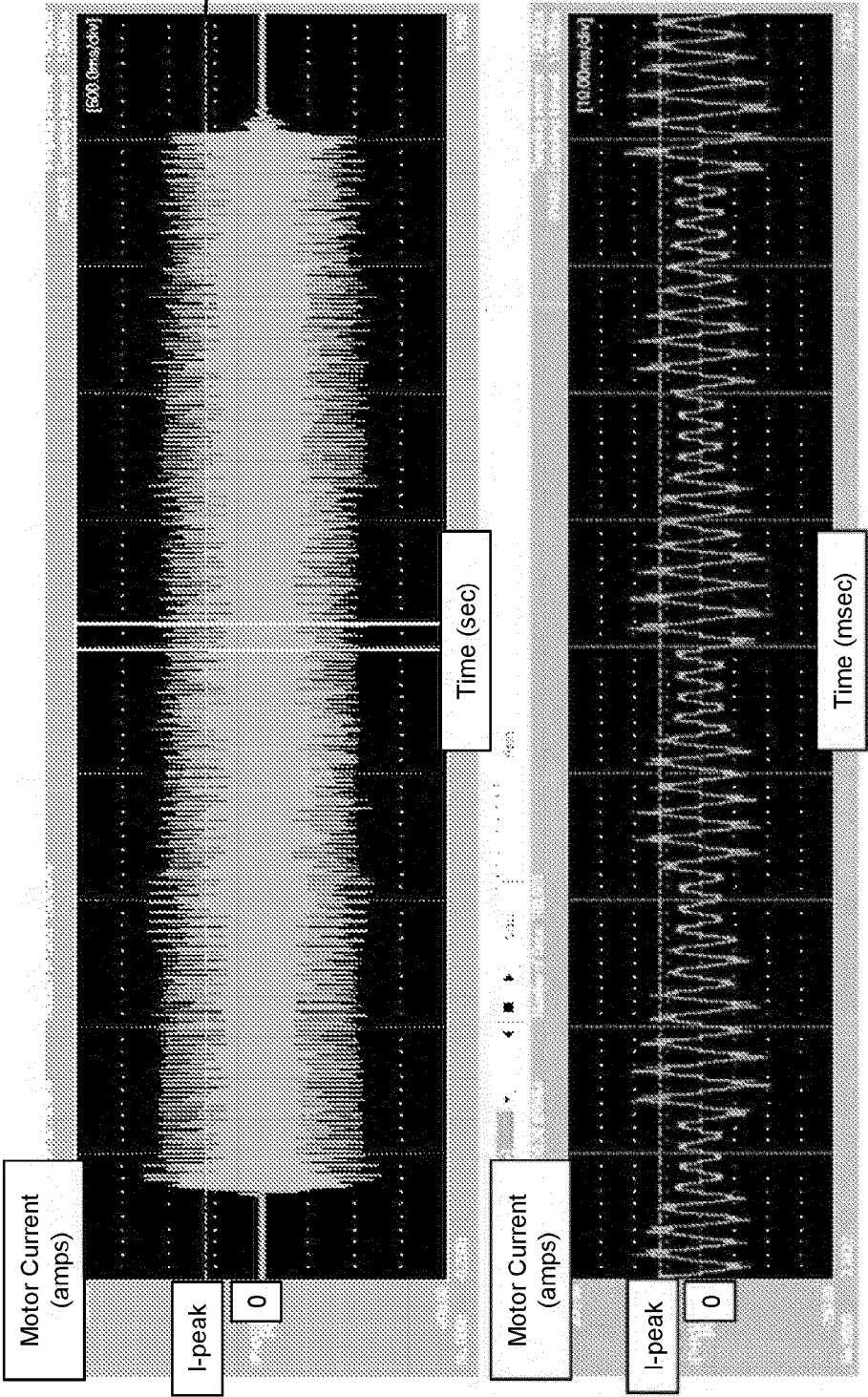


FIG. 16

Control Mode 7 (Protection Mode)

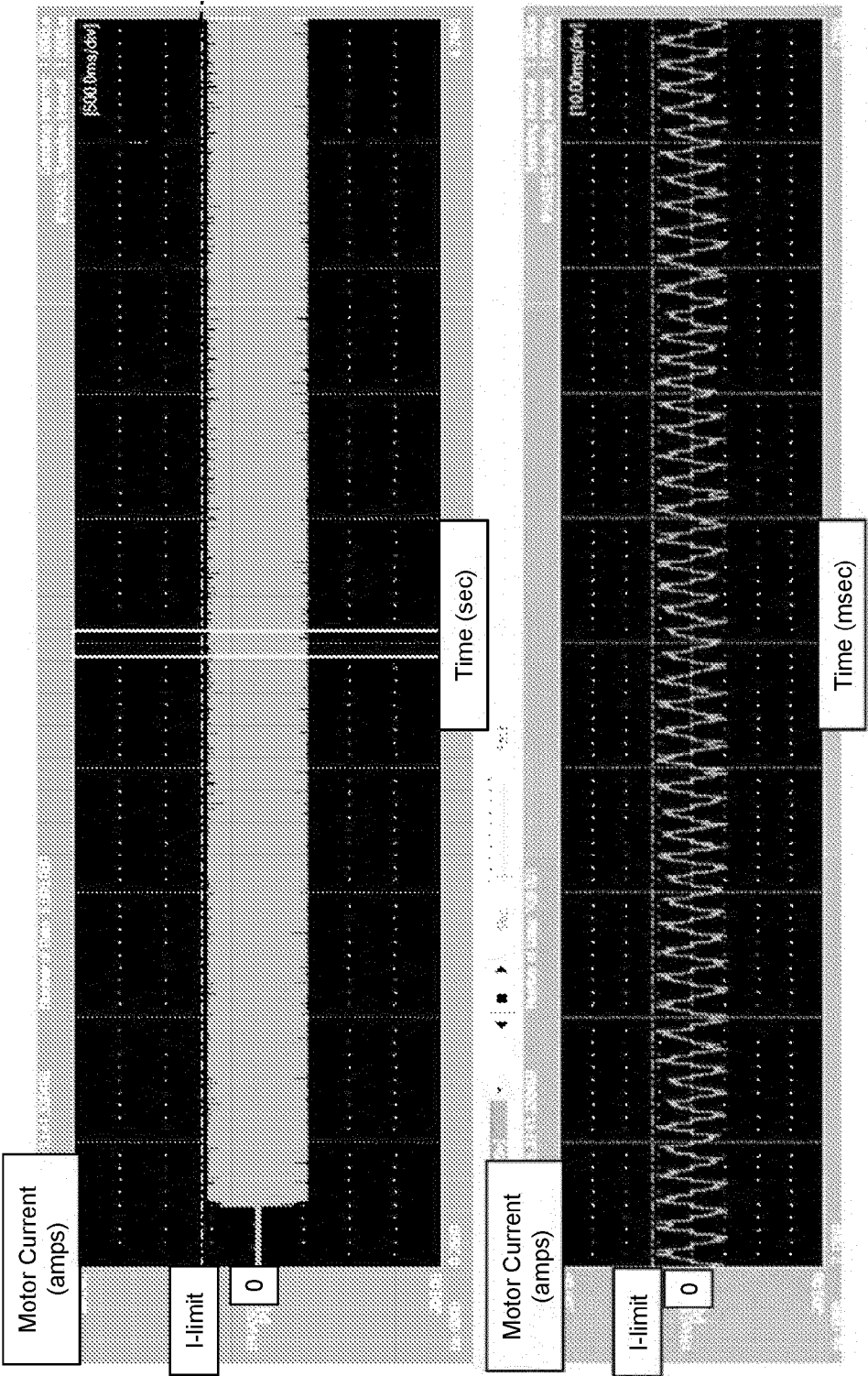


FIG. 17

Control Mode 7 (Protection Mode)

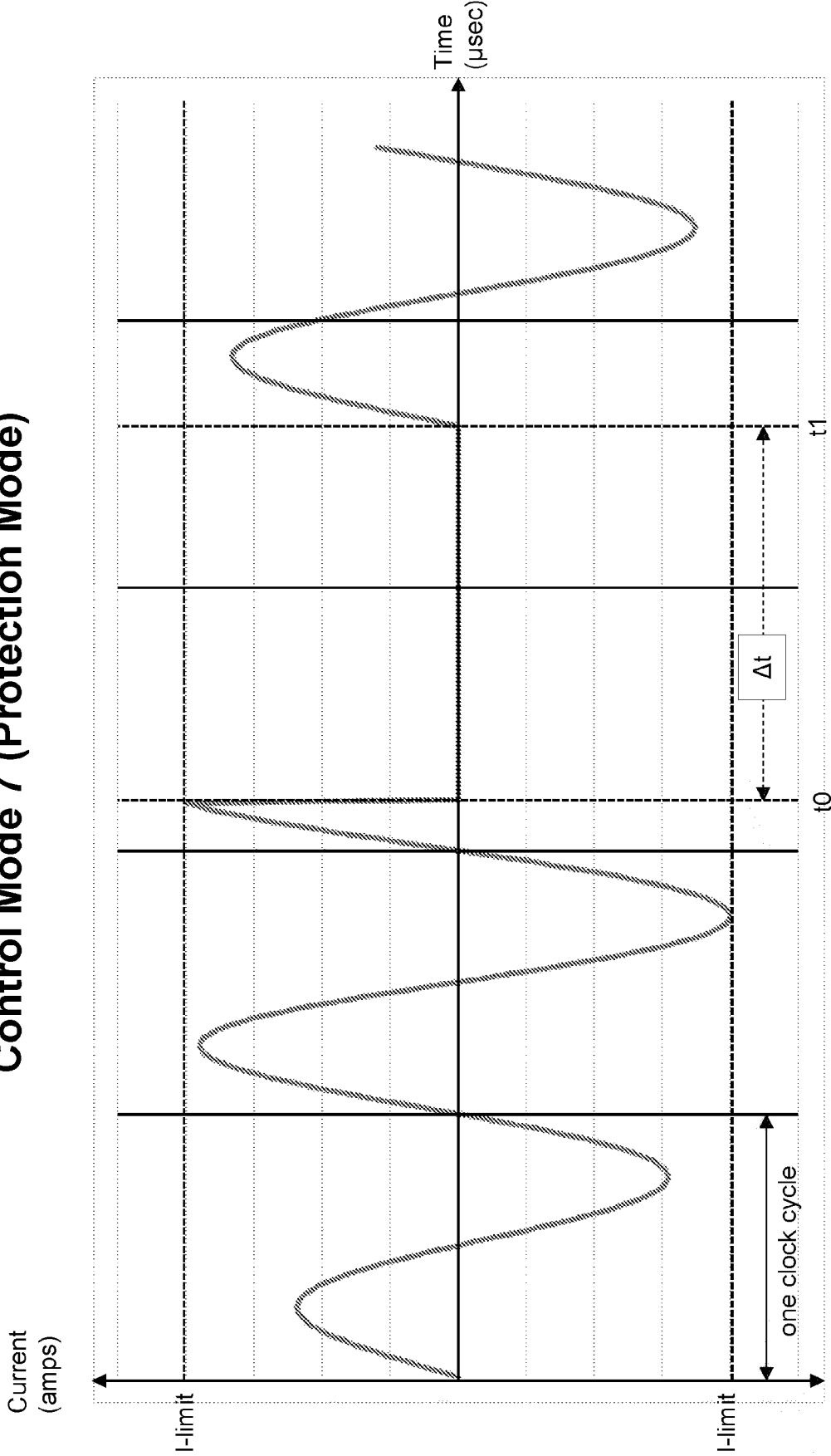


FIG. 18

Control Mode 7 (Protection Mode)

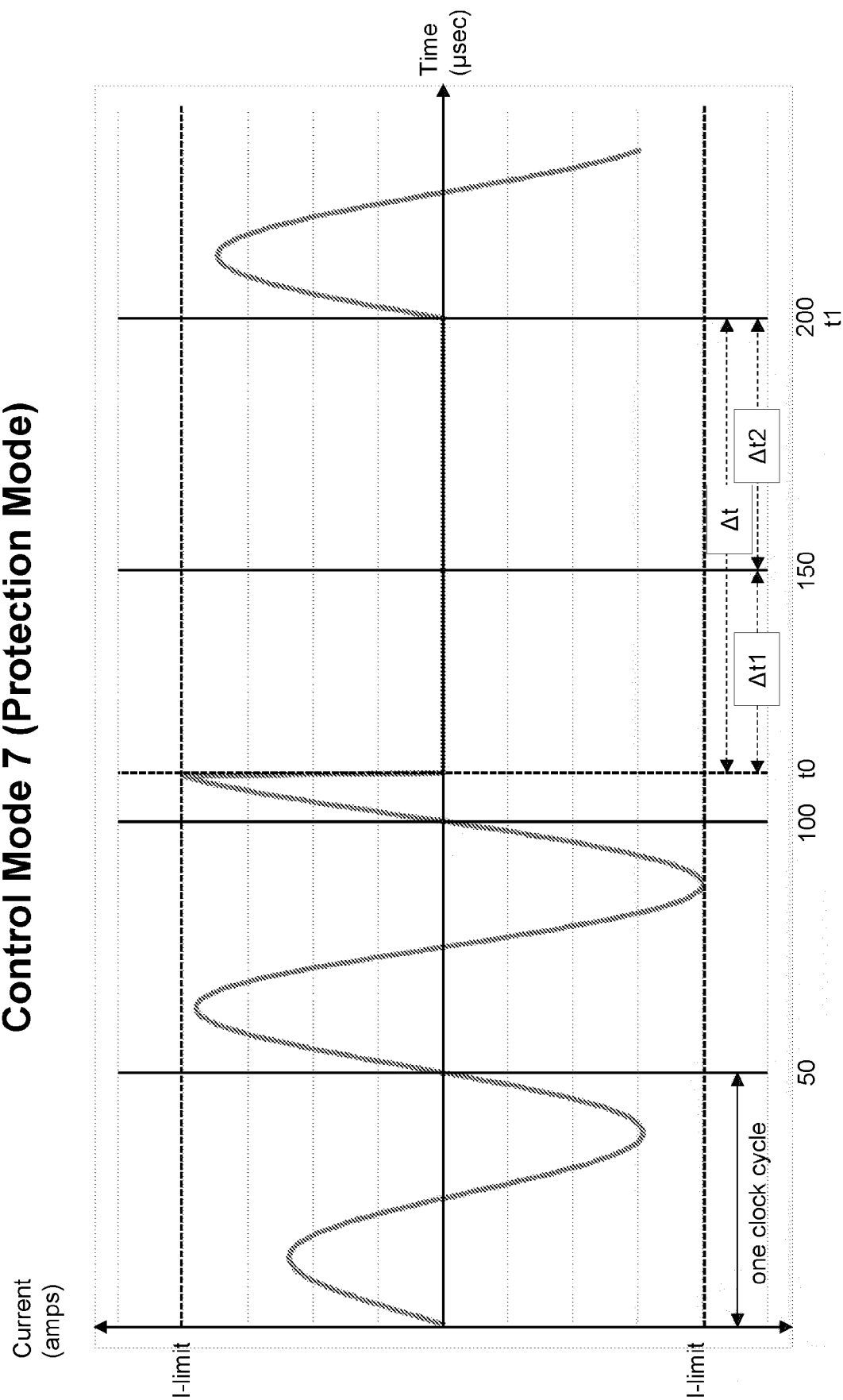


FIG. 19

Control Mode 7 (Protection Mode)

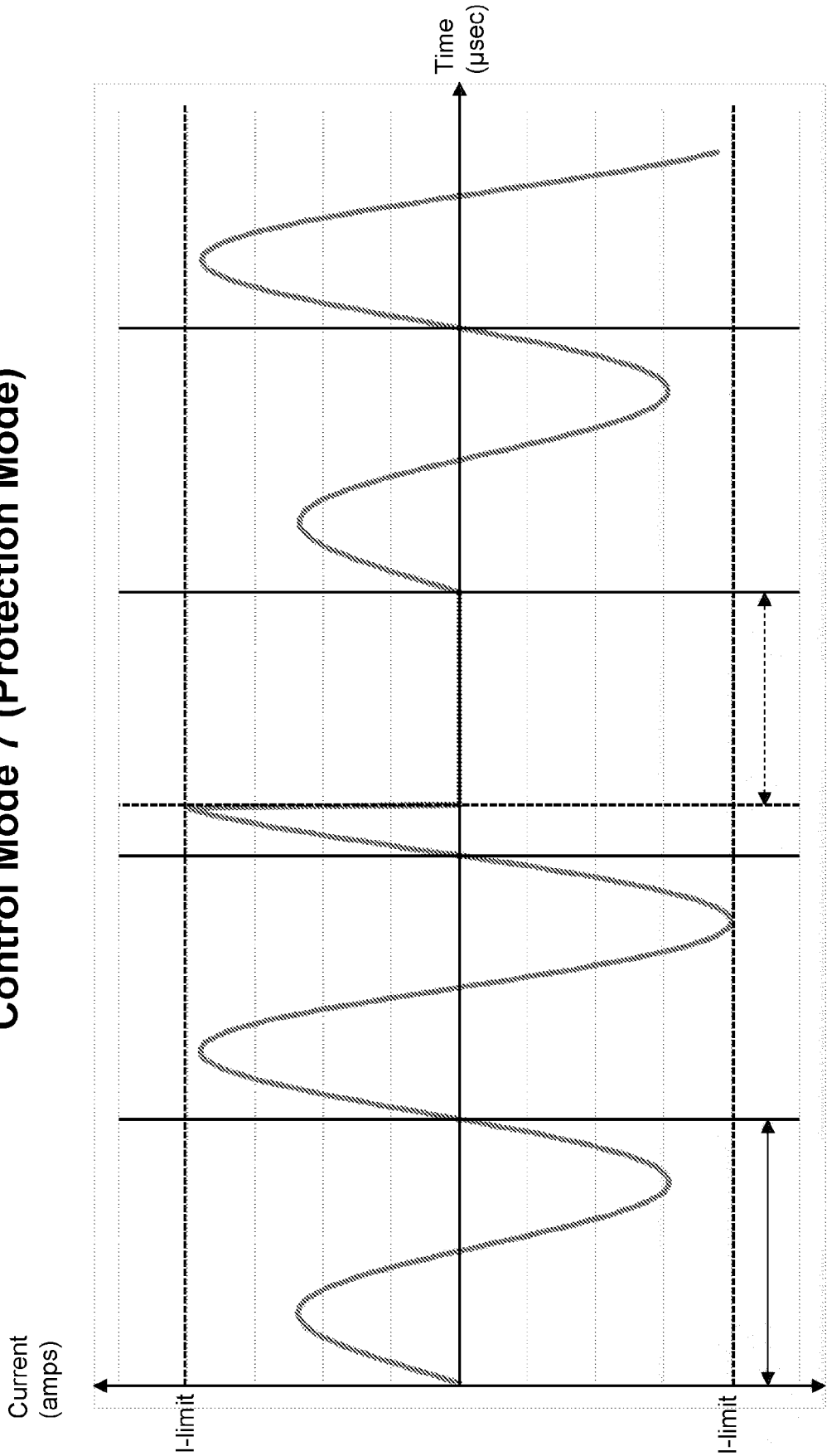


FIG. 20

Control Mode 8 (Enhanced Mode – First Direction)

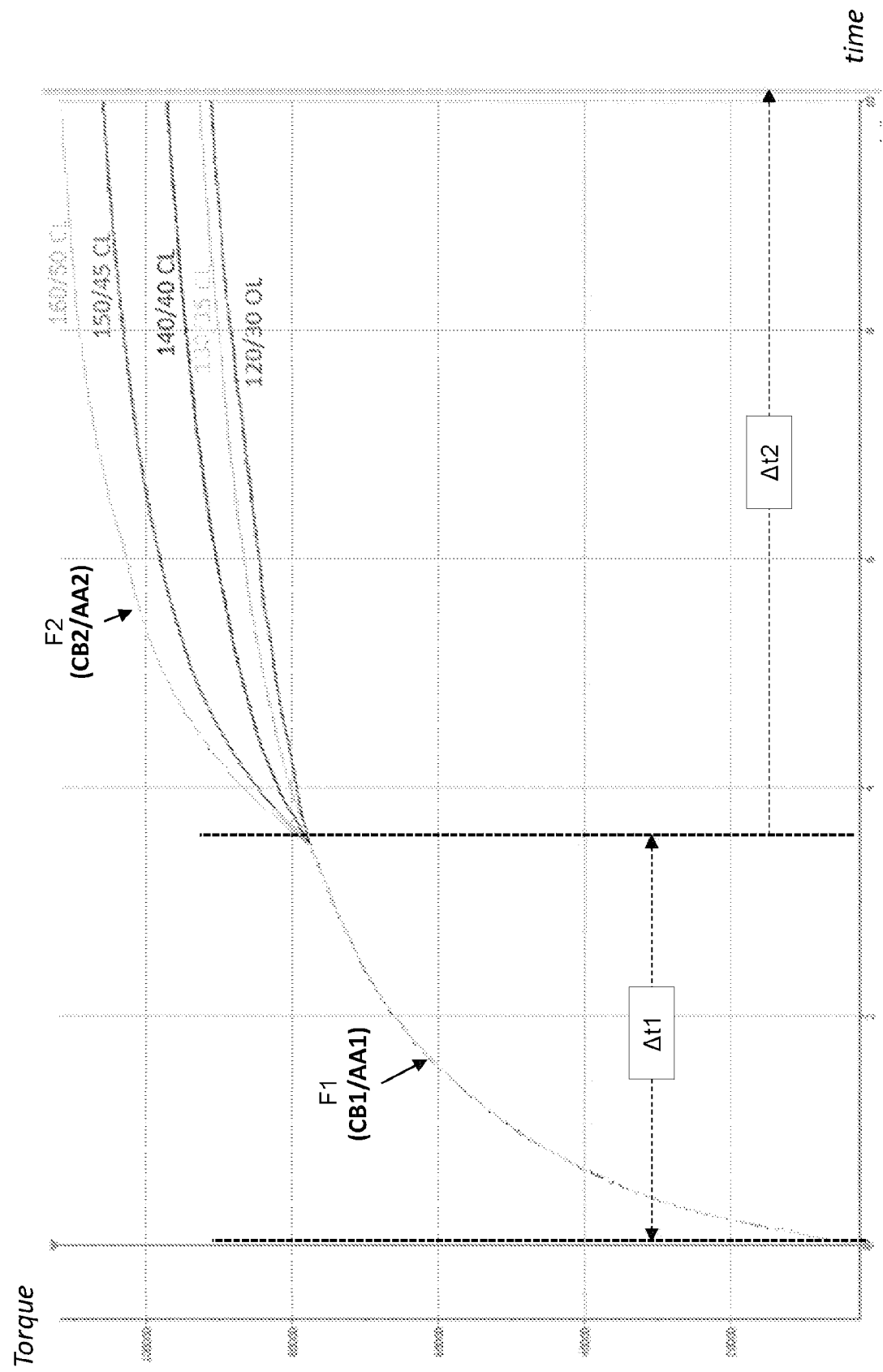


FIG. 21

Control Mode 8 (Enhanced Mode – First Direction)

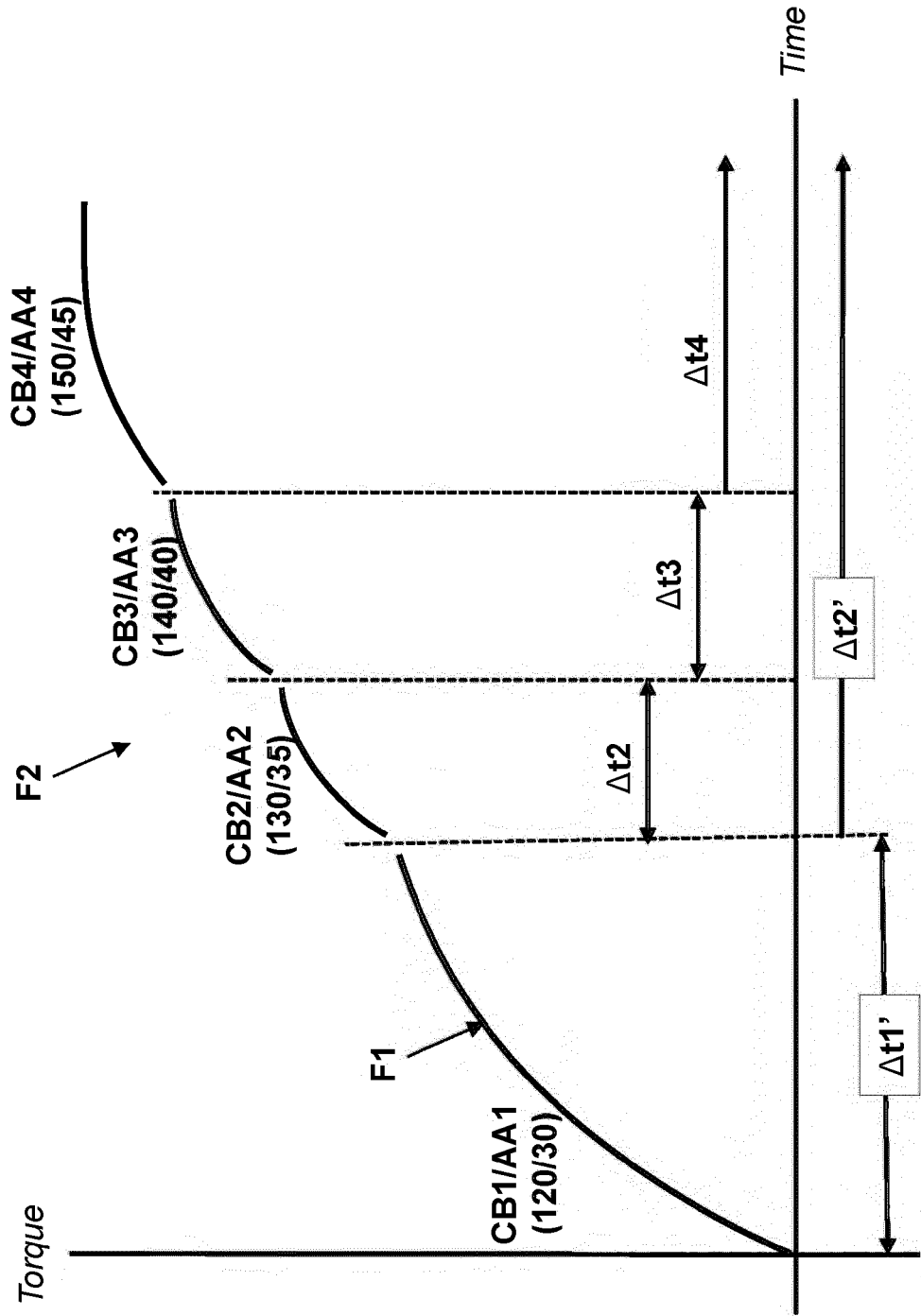


FIG. 21A

Control Mode 8 (Enhanced Mode – First Direction)

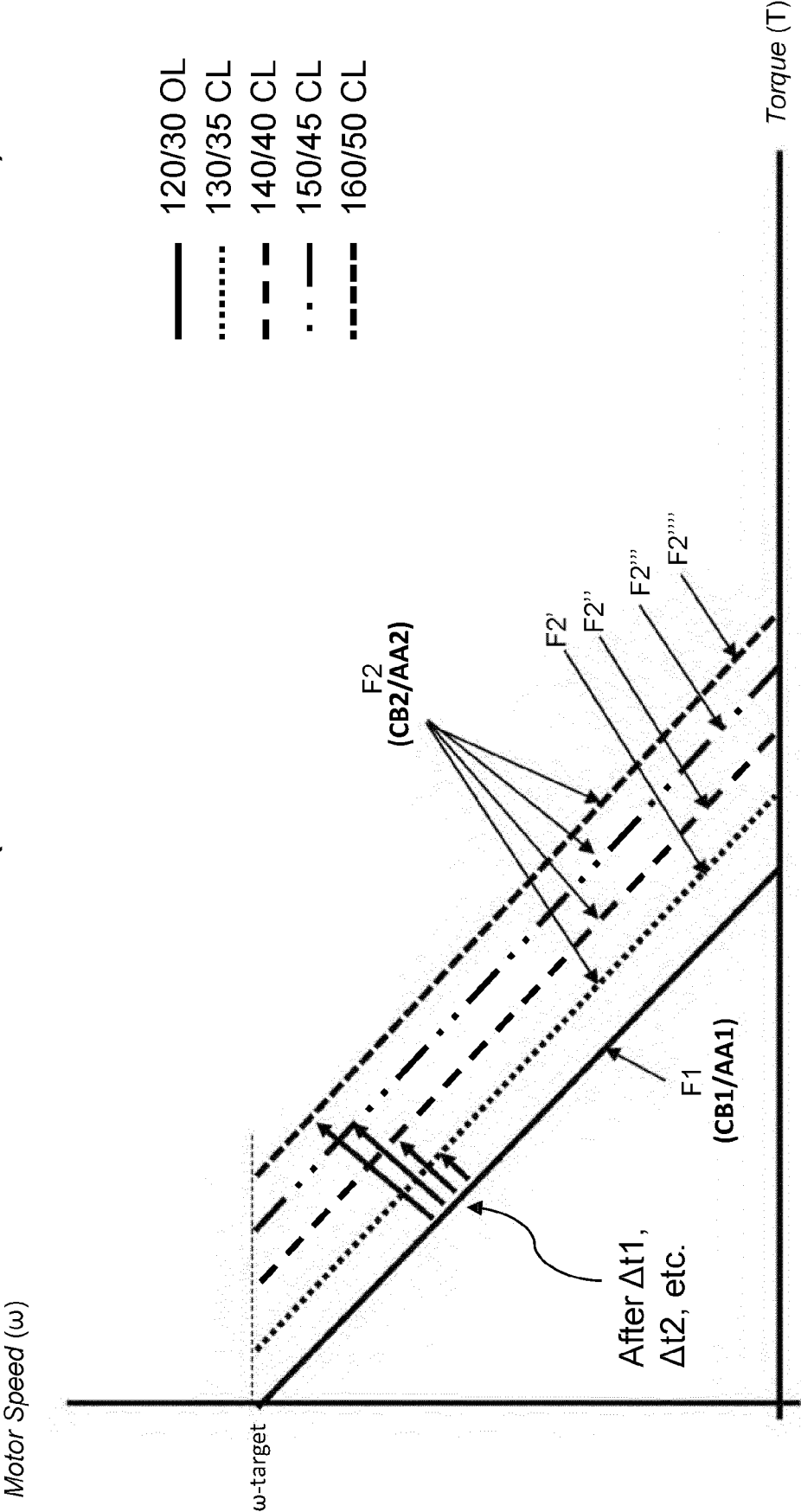


FIG. 21B

Control Mode 8 (Enhanced Mode – Second Direction)

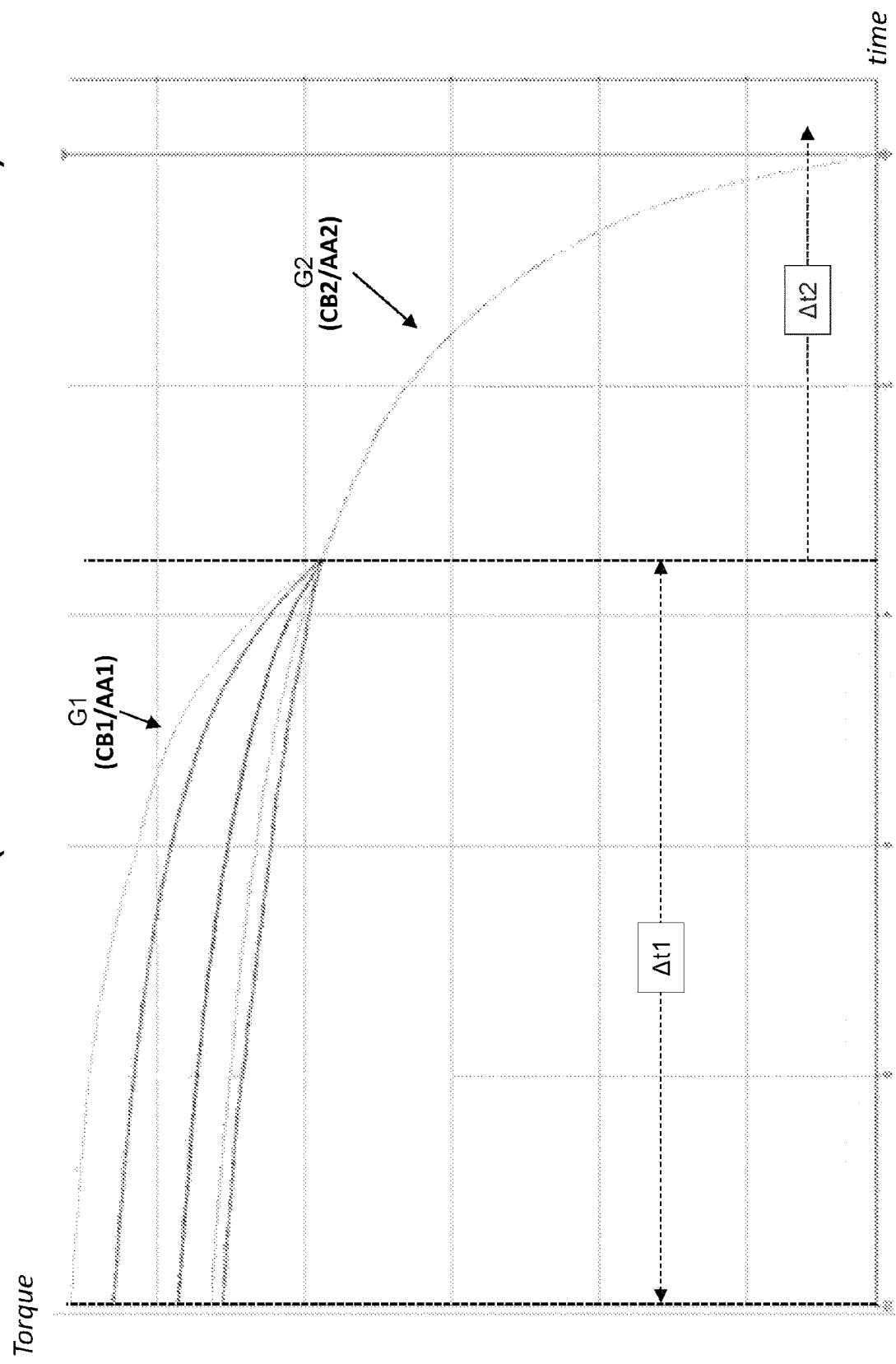


FIG. 22

Control Mode 8 (Enhanced Mode – Second Direction)

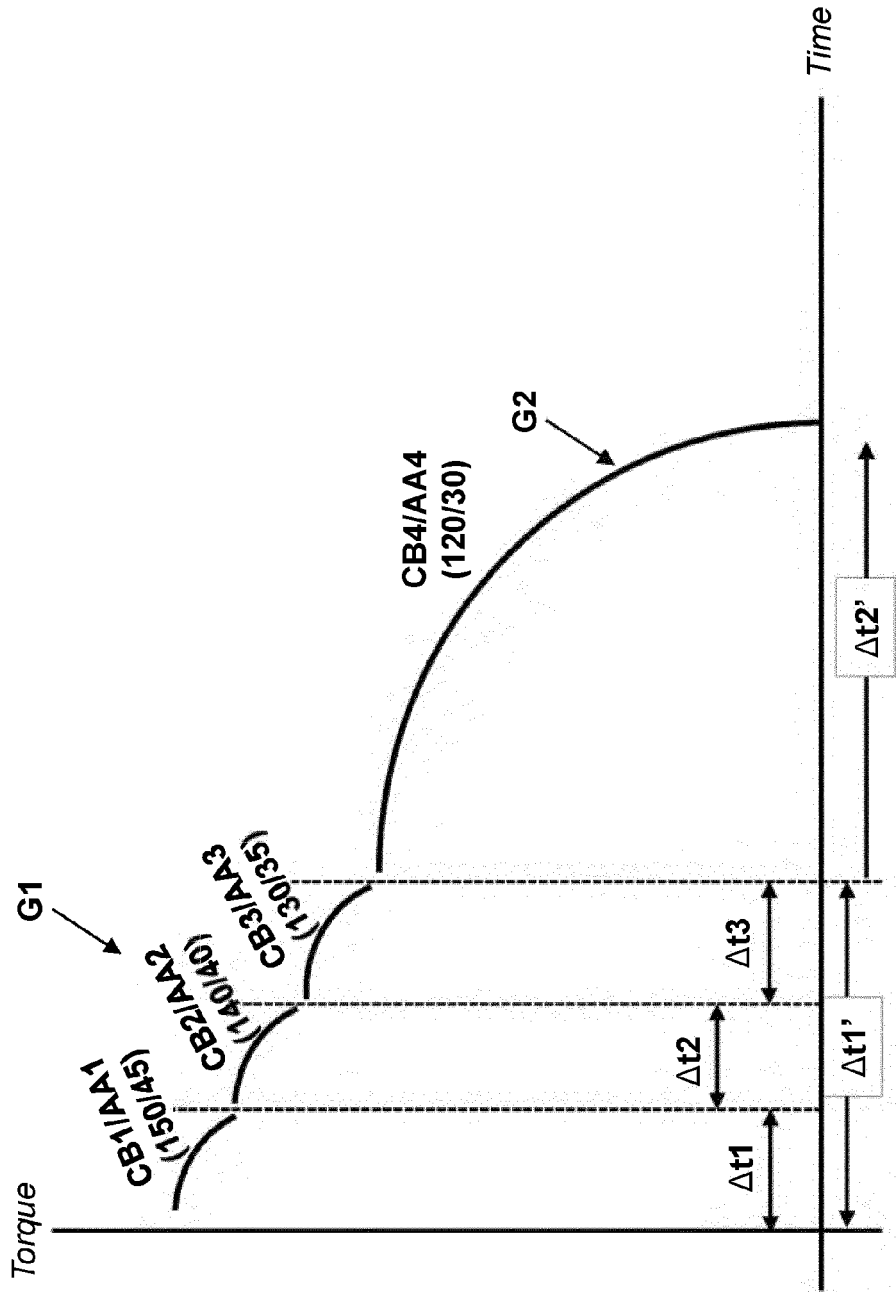


FIG. 22A

Control Mode 8 (Enhanced Mode – First Direction)

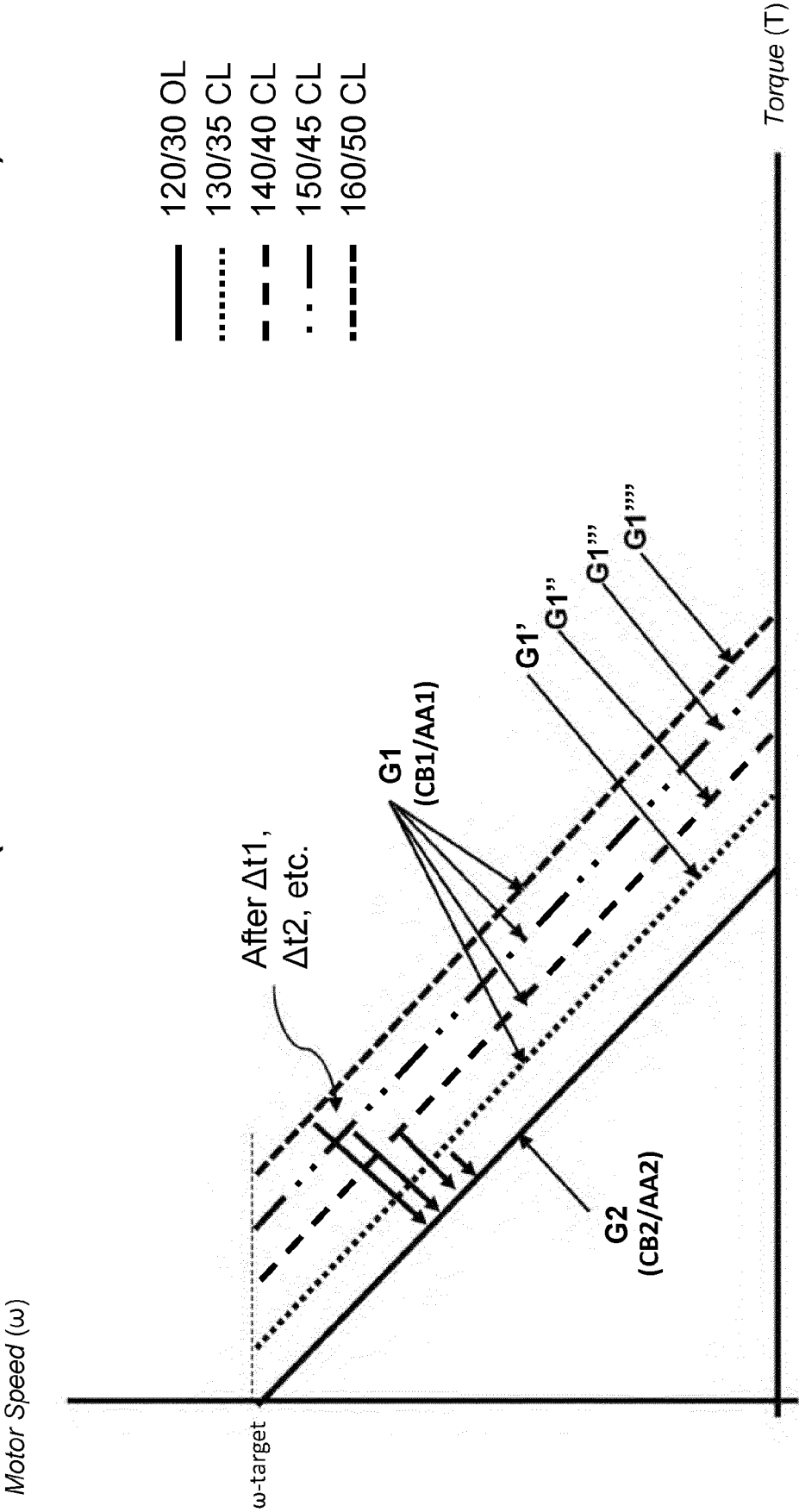


FIG. 22B

Control Mode 9
(Precision Enhanced Mode
First Embodiment)

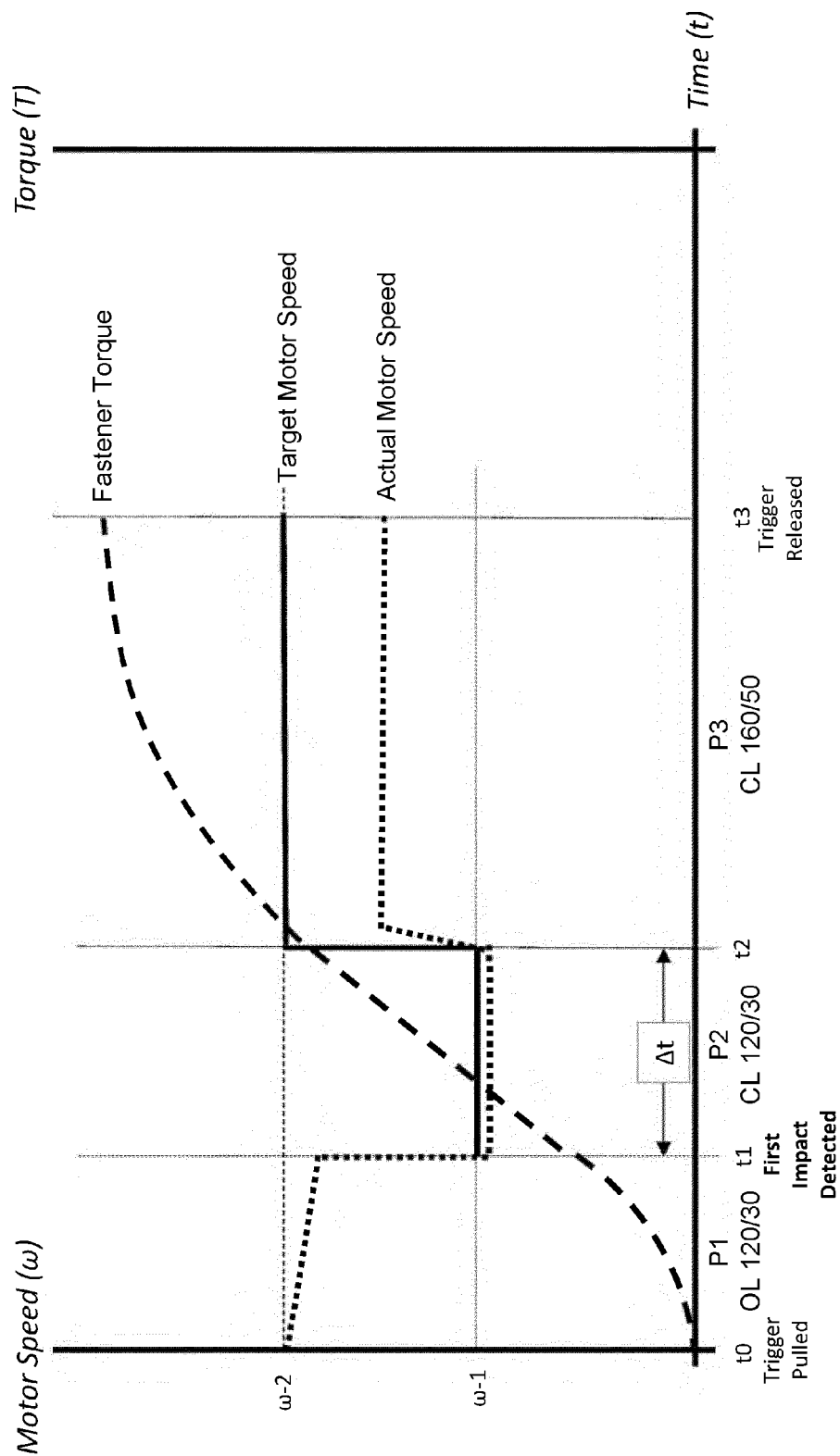


FIG. 23A

Control Mode 9
(Precision Enhanced Mode
Second Embodiment)

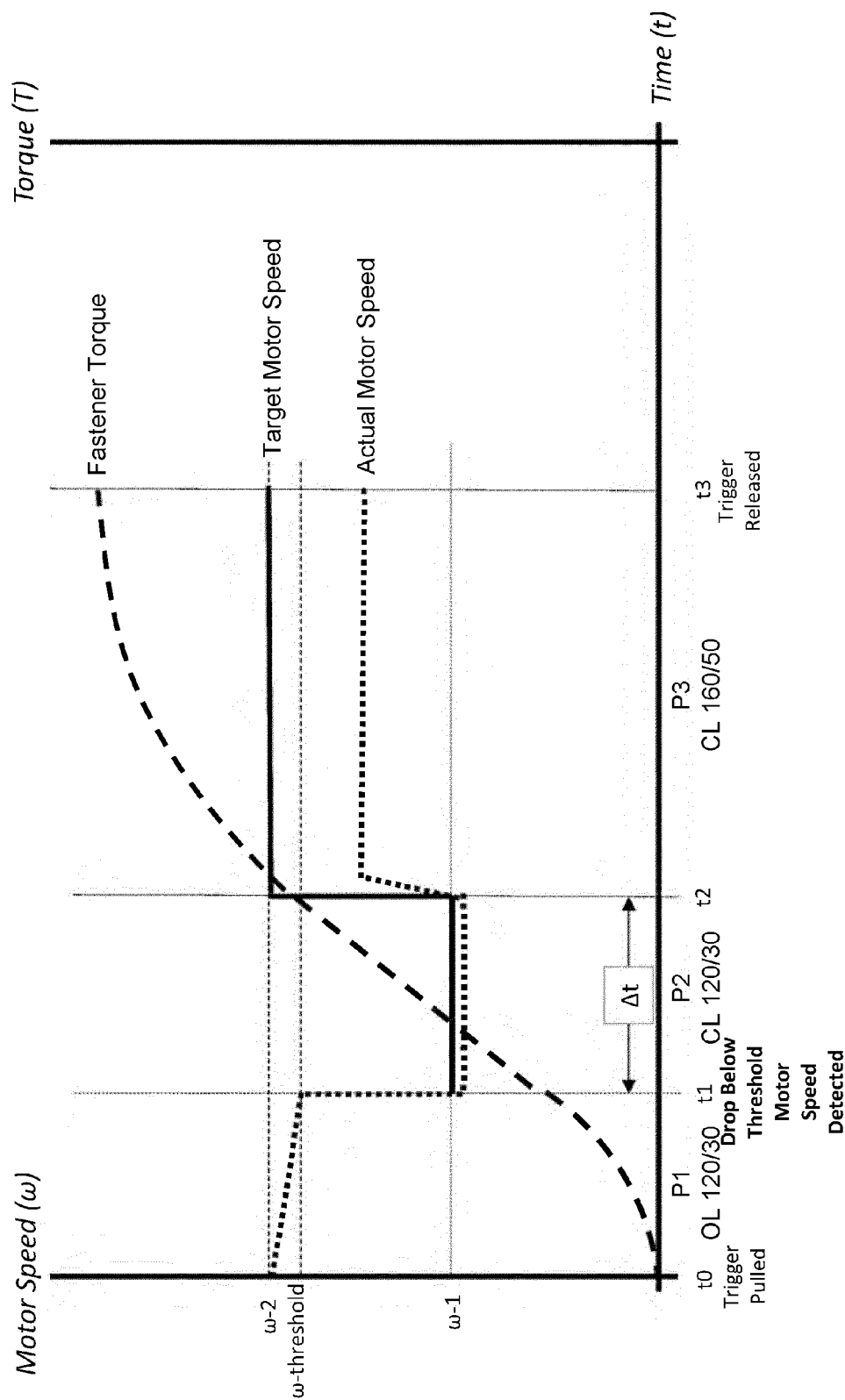


FIG. 23B

Control Mode 10 (Enhanced Mode) Tightening Fastener

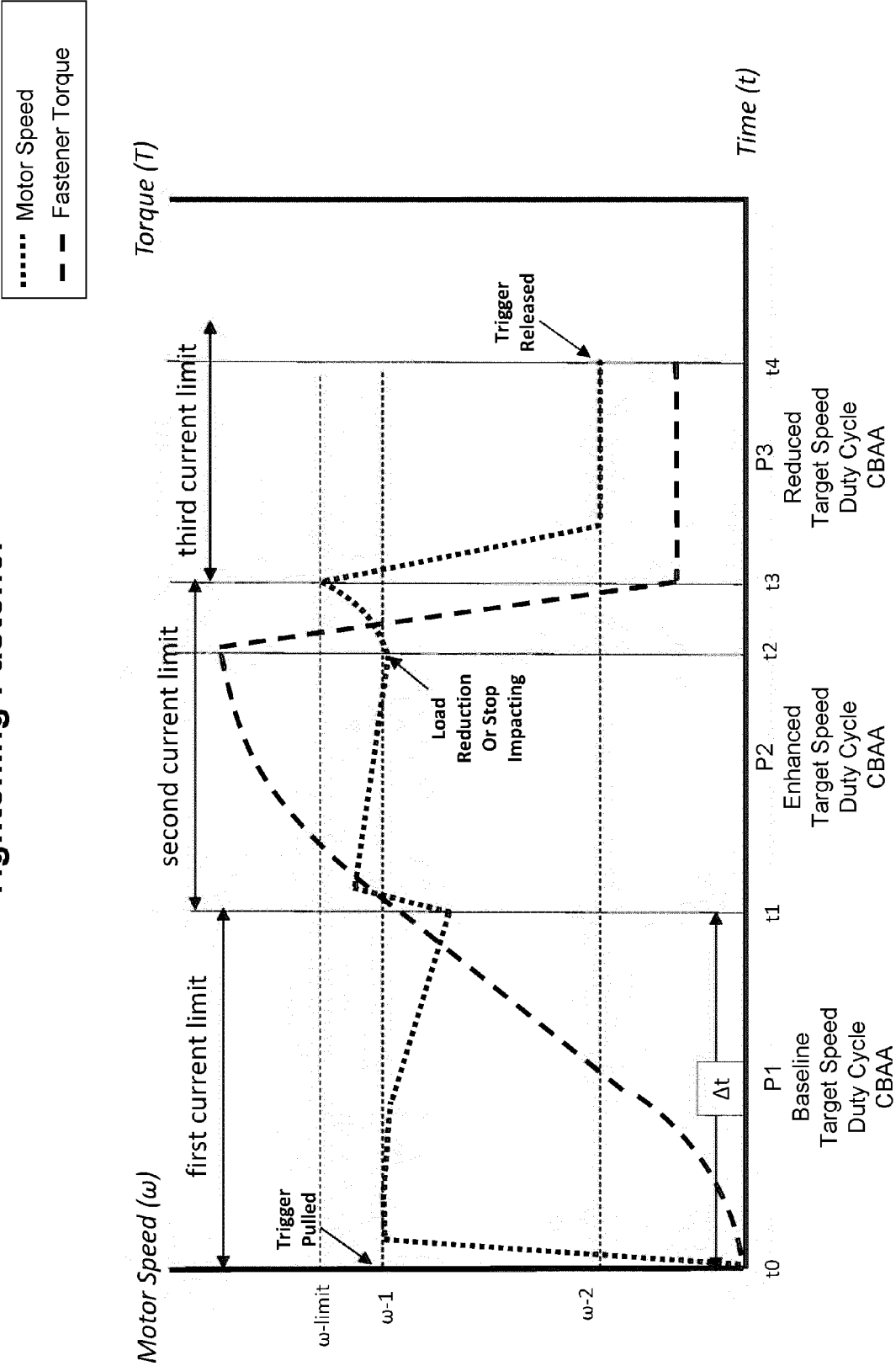


FIG. 24A

Control Mode 10 (Enhanced Mode) Loosening Fastener

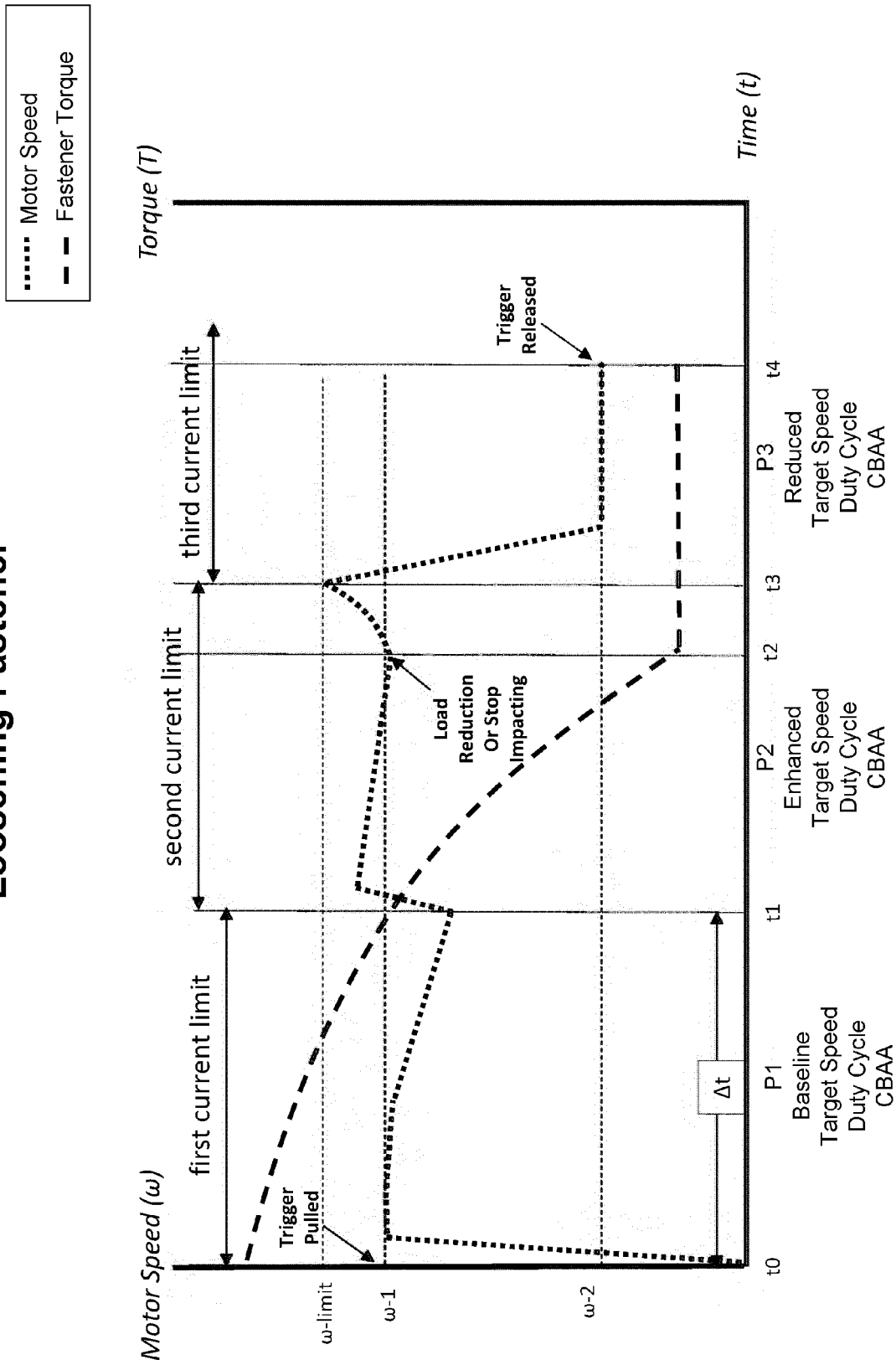


FIG. 24B

Control Mode 11 (Enhanced Mode) Tightening Fastener

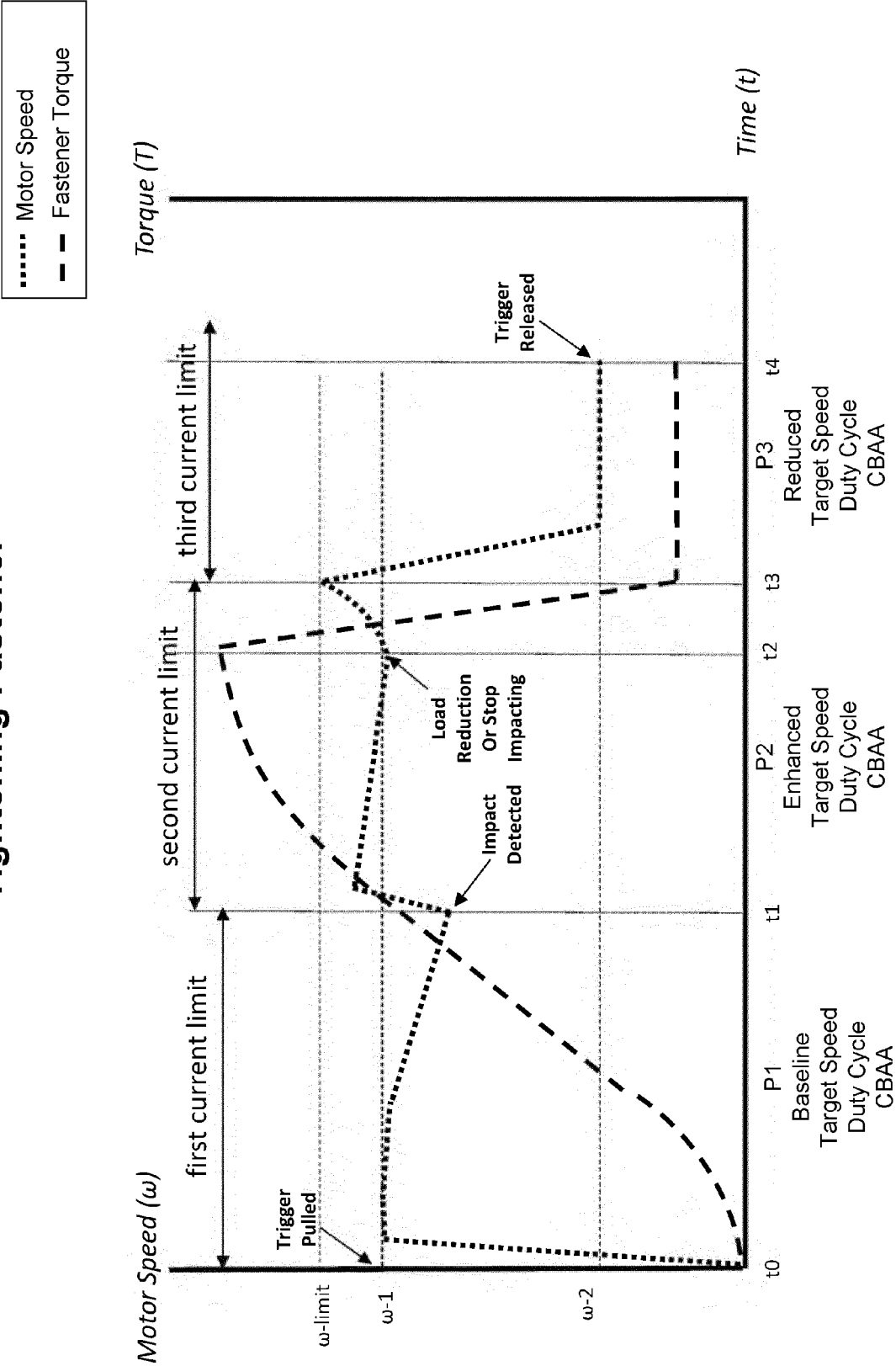


FIG. 25A

Control Mode 11 (Enhanced Mode) Loosening Fastener

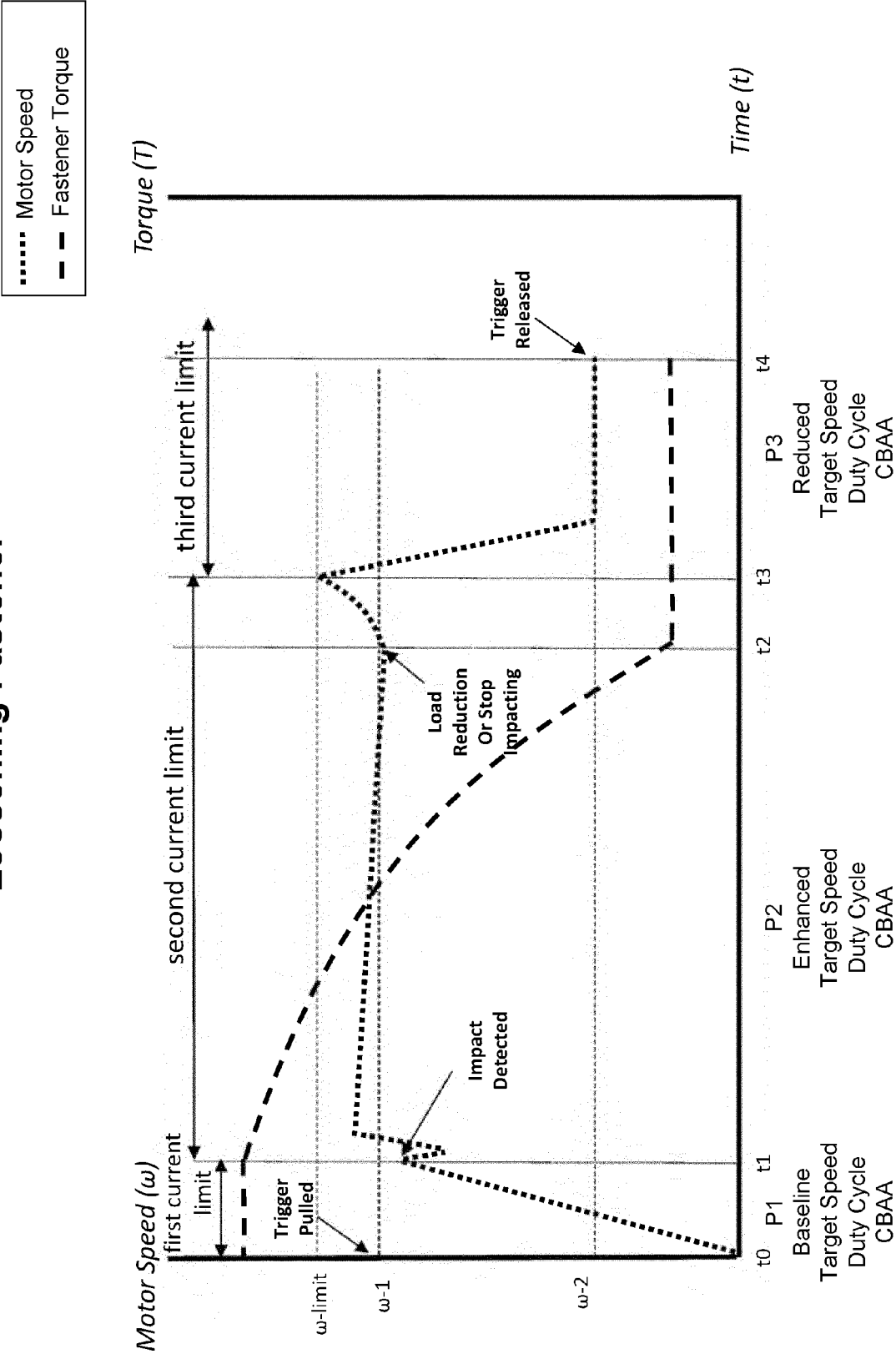


FIG. 25B

Control Mode 12 (Precision Enhanced Mode) Tightening Fastener

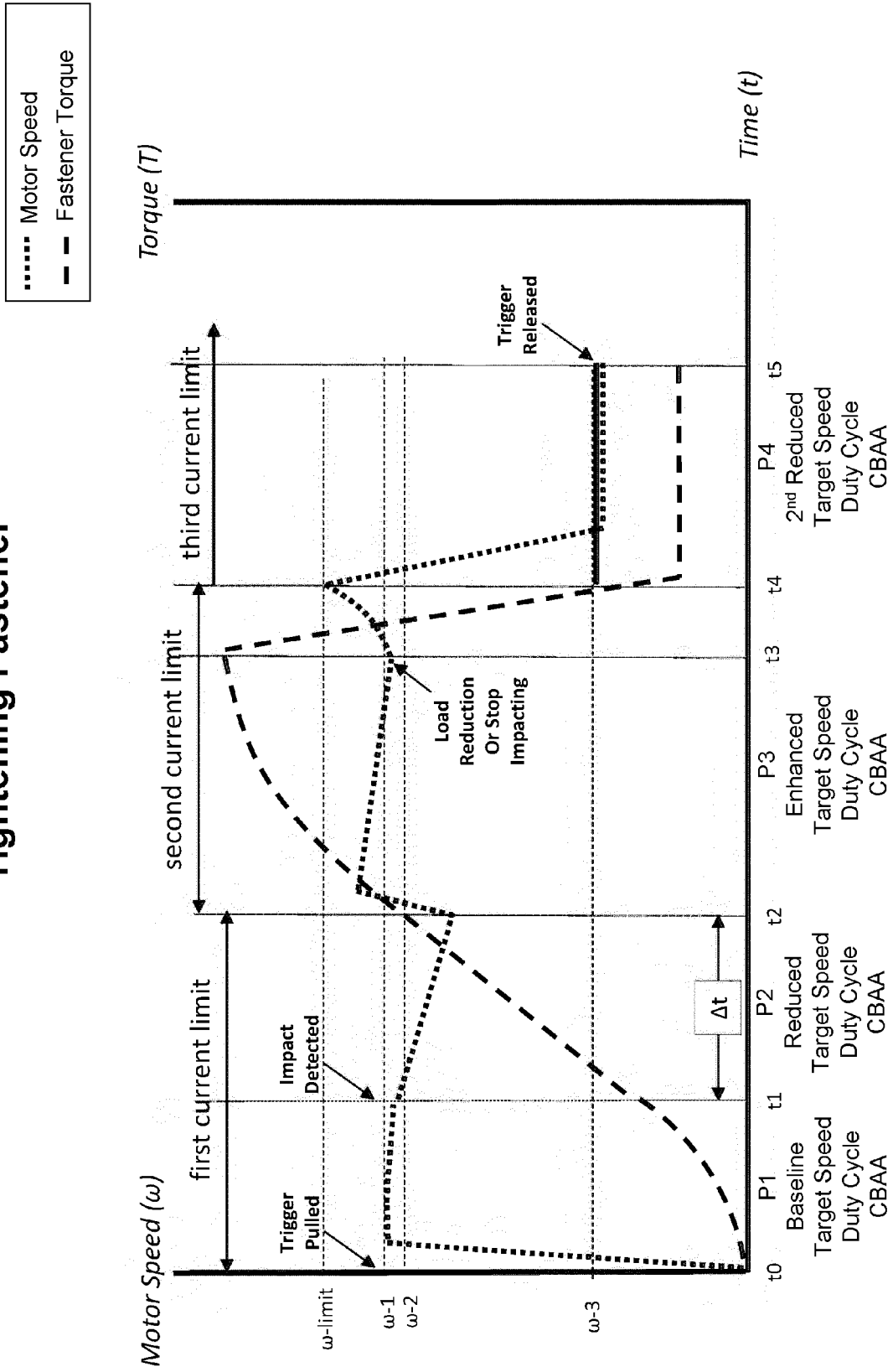


FIG. 26A

Control Mode 12 (Precision Enhanced Mode) Loosening Fastener

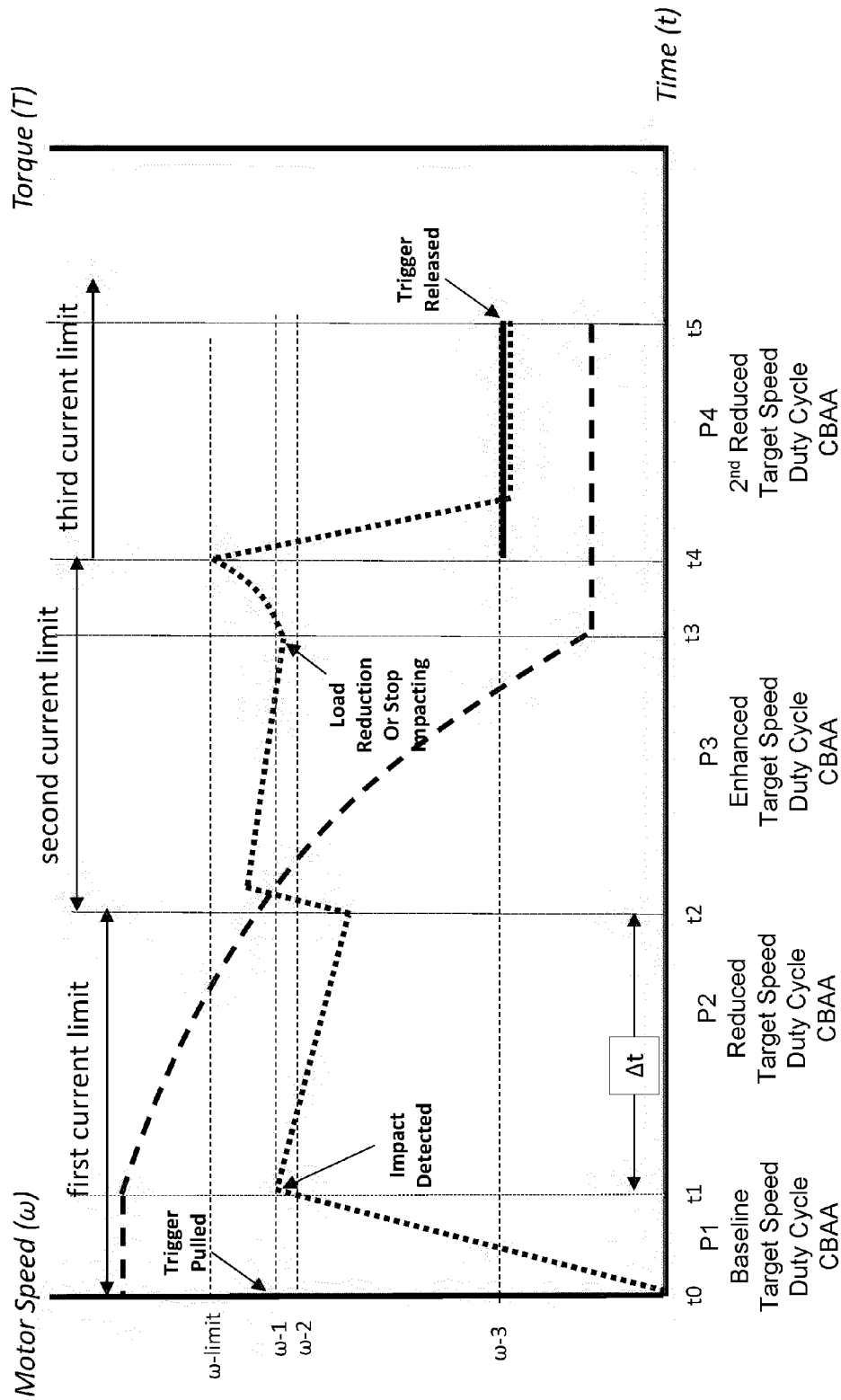
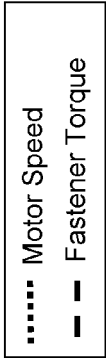


FIG. 26B

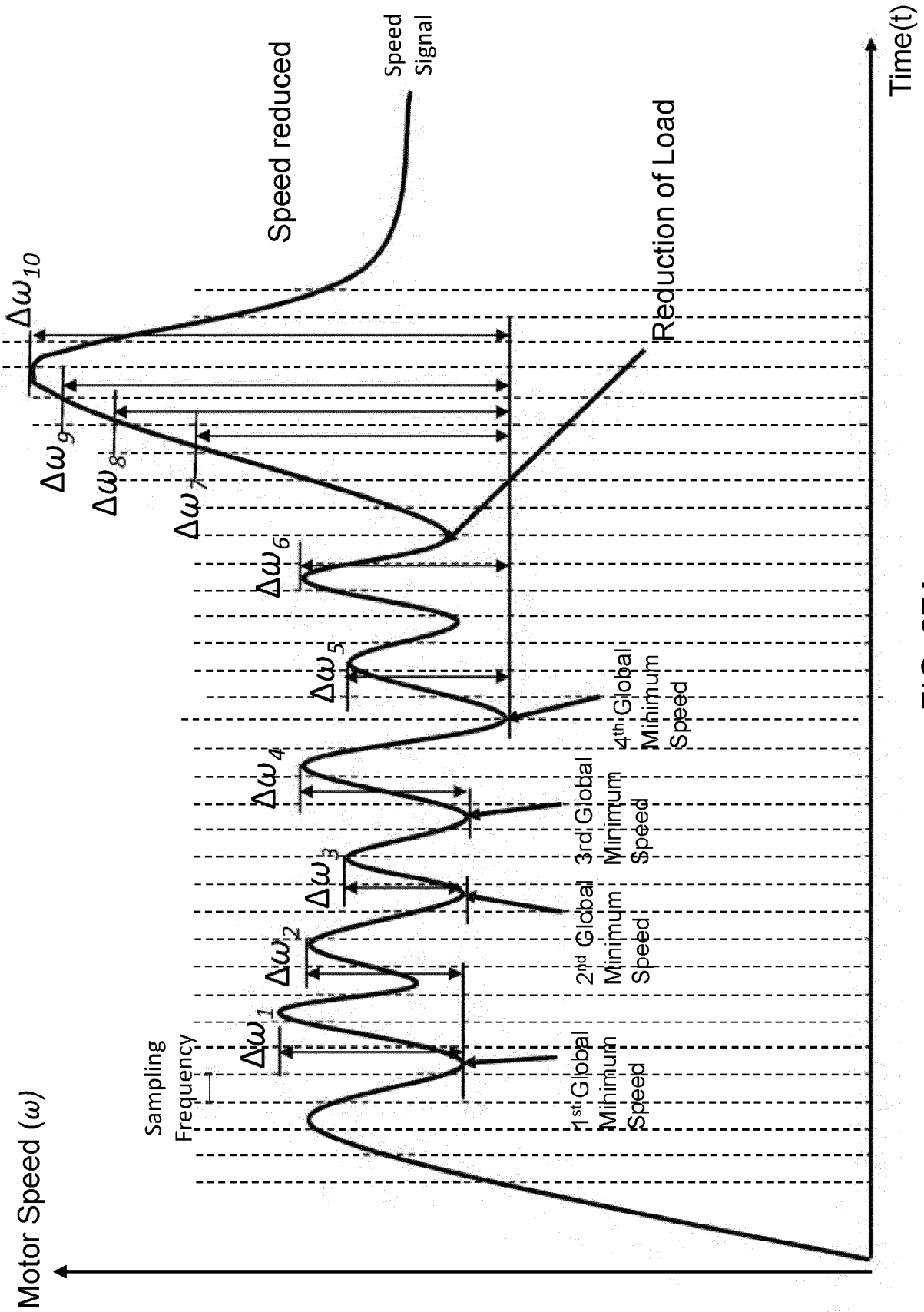


FIG. 27A

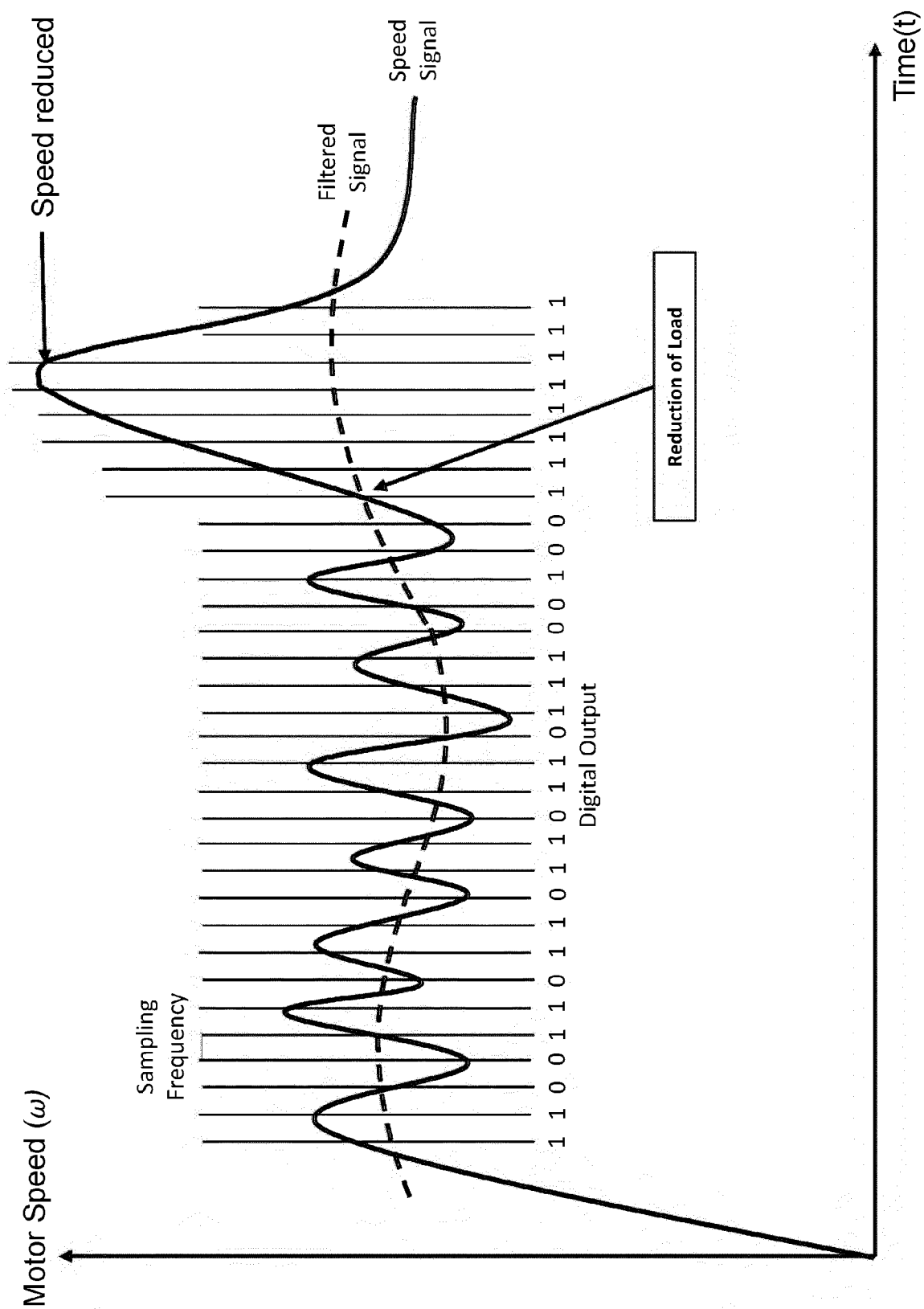


FIG. 27B



EUROPEAN SEARCH REPORT

Application Number

EP 23 18 0615

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2022/200511 A1 (FRIEDMAN BRIAN E [US] ET AL) 23 June 2022 (2022-06-23) * paragraphs [0181], [0183], [0184]; figure 23a *	1-15	INV. B25B21/02 B25B23/147
A	US 2016/250738 A1 (LEH JASON K [US] ET AL) 1 September 2016 (2016-09-01) * page 7, right-hand column, lines 5,6 * * paragraphs [0054], [0057], [0060], [0066]; figure 6c *	1,9,14	
			TECHNICAL FIELDS SEARCHED (IPC)
			B25B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		13 October 2023	Matzdorf, Udo
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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 23 18 0615

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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13-10-2023

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