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(54) **Title**: A STEERING APPARATUS FOR A STEERED VEHICLE

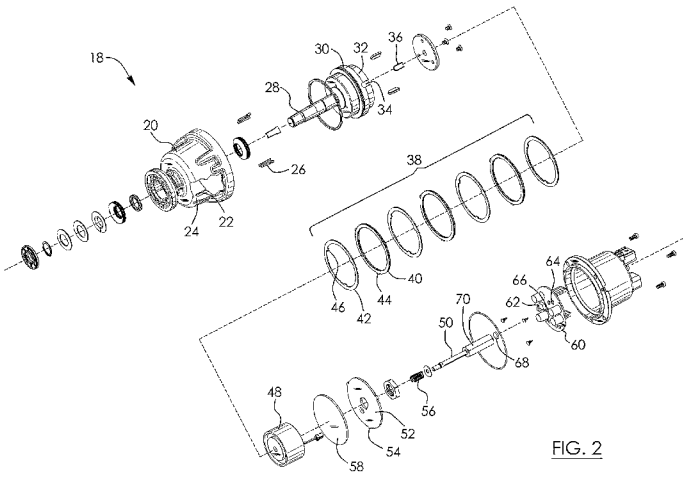

FIG. 2

(57) **Abstract**: A steering apparatus comprises a rotatable steering shaft and a sensor which senses angular movement of the steering shaft. An electromagnetic actuator actuates a stop mechanism to releasable engage the steering shaft. There is a microcontroller which causes the electromagnetic actuator to actuate the stop mechanism to fully engage the steering shaft and prevent rotation of the steering shaft in a first rotational direction, which corresponds to movement towards the hardstop position, while allowing rotational play between the steering shaft and the stop mechanism in a second direction, which corresponds to rotational movement away from the hardstop position, when the sensor senses that the steering shaft has reached a hardstop position. A driver applies a reserve polarity pulse to the electromagnetic actuator when the stop mechanism is fully engaged and the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction.

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A STEERING APPARATUS FOR A STEERED VEHICLE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of provisional application 61/598,701 filed in the United States Patent and Trademark Office on February 14, 2012, the disclosure of which is incorporated herein by reference and priority to which is claimed.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates toa steering apparatus and, in particular, to a steering apparatus for a steered vehicle.

Description of the Related Art

[0003] United States 7,137,347 which issued on November 21, 2006 to Wong et al. discloses helm apparatus for a marine vessel or other vehicle having a steered member such as a rudder. The helm apparatus includes a mechanically rotatable steering device and a sensor which senses angular movement of the steering device when the marine vessel is steered. A communication link to the rudder enables the helm apparatus to monitor the rudder position. A bi-directional stop mechanism is actuated when the helm apparatus determines that the rudder position is beyond starboard or port hard-over thresholds, indicating that the rudder has reached a limit of travel. The helm apparatus can cause the stop mechanism to fully engage the steering device to stop further rotation of the steering device in a first rotational direction, corresponding to rotational movement towards the limit of travel.

SUMMARY OF THE INVENTION

[0004] It is an object of the present invention to provide an improved steering apparatus for a steered vehicle. The steered vehicle may be a land vehicle or a marine vehicle.

[0005] There is accordingly provided a steering apparatus for a steered vehicle. The steering apparatus comprises a rotatable steering shaft and a sensor which senses angular movement of the steering shaft as the vehicle is being steered. An electromagnetic actuator actuates a stop mechanism to releasably engage the steering shaft. There is a microcontroller which processes a steering sensor signal and causes the electromagnetic actuator to actuate the stop mechanism to fully engage the steering shaftwhen the sensor senses that the steering shaft has reached a hardstop position to prevent rotation of the steering shaft in a first rotational direction, which corresponds to movement towards the hardstop position, while allowing rotational play between the steering shaft and the stop mechanism in a second direction, which corresponds to rotational movement away from the hardstop position. A driver applies a reserve polarity pulse to the electromagnetic actuator when the stop mechanism is fully engaged with the steering shaft and the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction.

[0006] The driver may apply thereserve polarity pulse at a moment when the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction. The microcontroller may cause the electromagnetic actuator to actuate the stop mechanism to release the steering shaft when the stop mechanism is fully engaged with the steering shaft and the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction. The microcontroller may cause the electromagnetic actuator to actuate the stop mechanism to partially engage the steering shaft to provide steering resistance.

[0007] The stop mechanism may include a multi-plate clutch having a plurality of clutch plates which are urged into frictional engagement with each other by the electromagnetic actuator to engage the steering shaft. There may be a housing with a hollow interior and there may be grooves on an interior wall of the housing. A first type of clutch plates may have projections which fit within the grooves on the interior wall of the housing. There may be inserts in the grooves on the interior wall of the housing. There may be grooves on the steering shaft wherein a second type of clutch plates have projections which fit within the grooves in the steering shaft. The grooves on the steering shaft may be wider than the projections on the second type of clutch plates to allow for the rotational play between the steering shaft and the stop mechanism when the stop mechanism is fully engaged. There may be inserts in the grooveson the steering shaft.

[0008] The electromagnetic actuator may include anelectromagnetic coil mounted on a mounting plate and an armature. The clutch plates may be disposed between the mounting plate and the armature. There may be aspring which preloads the clutch plates for improved gap control. There may be ashim between the electromagnetic coil and the mounting plate to set the electromagnetic coil and the mounting plate at a predetermined clearance. The steered vehicle may be a land vehicle or a marine vehicle.

BRIEF DESCRIPTIONS OF DRAWINGS

[0009] The invention will be more readily understood from the following description of the embodiments thereof given, by way of example only, with reference to the accompanying drawings, in which:

[0010] Figure 1 is a perspective view of a marine vehicle provided with an improved steering apparatus;

[0011] Figure 2 is an exploded view of thesteering apparatus of Figure 1;

[0012] Figure 3 is a diagrammatic view of the steering apparatus of Figure 1;

[0013] Figures 4A to 5C are schematics of switches integrated into the H-driver bridge of the steering apparatus of Figure 1;

[0014] Figure 5aregraphsillustrating H-Bridge PWM control logic of the steering apparatus of Figure 1;

[0015] Figure 6 is a state diagram of the control logic of the steering apparatus of Figure 1; and

[0016] Figure 7 is a perspective view of a land vehicle provided with the improved steering apparatus.

DESCRIPTIONS OF THE PREFERRED EMBODIMENTS

[0017] Referring to the drawings and first to Figure 1, this shows a vehicle in the form of a marine vessel 10 which is provided with propulsion units in the form of outboard engines 12a and 12b. In this example there are two engines, namely, a port engine 12a and a starboard engine 12b. However, in other examples, the marine vessel may be provided with any suitable number of engines. It is common to haveone engine or as many as five engines in pleasure marine vessels. The marine vessel 10 is also provided with a control station 14 that supports a steering wheel 16 mounted on a helm orsteering apparatus18. The steering wheel 16 is conventional and the steering apparatus 18is shown in greater detail in Figure 2.

[0018] The steering apparatus 18 is improved over the helm disclosed in United States Patent Number 7,137,347 which issued on November 21, 2006 to Wong et al. and the full disclosure of which is incorporated herein by reference. The steering apparatus 18 includes a housing 20 which is shown partially broken away in Figure 2. There is a plurality of circumferentially spaced-apart axially extending grooves, for example groove

22, on an inner wall 24 the housing 20. There is also a plurality of resilient, channel-shaped inserts, for example insert 26, each of which is received by a corresponding one of the grooves on the inner wall of the housing. A steering shaft 28 extends through the housing 20. The steering wheel 16, shown in Figure 1, is mounted on the steering shaft 28. The steering shaft 28 includes a hollow drum portion 30 which has a cylindrical outer wall 32. There is a plurality of circumferentially spaced-apart grooves, for example groove 34, extending axially on the cylindrical outer wall 32 of the hollow drum 30. There is also a plurality of resilient, channel-shaped inserts, for example insert 36, each of which is received by a corresponding one of the grooves on the cylindrical outer wall of the hollow drum.

[0019] The steering apparatus 18 further includes a multi-plate clutch 38. There are two types of interposed substantially annular clutch plates in the multi-plate clutch 38. Clutch plate 40 is an exemplar of a first type of the clutch plate and clutch plate 42 is exemplar of a second type of clutch plate. The first type of clutch plate each have exterior projections, for example spline 44 shown for clutch plate 40, which are positioned to engage the grooves 22 on the inner wall 24 of the housing 20. The clutch plates 40 are thus axially slidable but non-rotational within the housing 20. The inserts 26 in the grooves 22 on the inner wall 24 of the housing 20may provide dampened motion and additional position control.The second type of clutch plate each have interior projections, for example spline 46 as shown for clutch plate 42, that are positioned to engage the grooves 34 on the cylindrical outer wall 32 of the hollow drum 30 of the steering shaft 28. The clutch plates 42 are thus axially slidable with respect to the steering shaft 28. A limited amount of rotational movement is also permitted between the clutch plates 42 and the steering shaft 28 because the grooves 34 on the steering shaft 28 are wider than the splines 46 on the clutch plates 42. The inserts 36 in the grooves 34 may provide dampened motion and additional position control.

[0020] Thesteering apparatus 18 further includes an actuator in the form of an electromagnetic actuator which, in this example, includes anelectromagnetic coil 48 and an armature 50. The electromagnetic coil 48 is mounted on a circular mounting plate 52.

The circular mounting plate has exterior projections, for example spline 54, which are positioned to engage the grooves 22 on the inner wall of the housing 20 such that the mounting plate 52 is axially slidable but non-rotational within the housing 20. The armature 50 is coupled to the steering shaft 28. When the electromagnetic coil 48 is energized, the electromagnetic coil 48 and the mounting plate 52 are drawn along the armature 50 to force the clutch plates 40 and 42 together. Since the first type of clutch plates 40 are non-rotatable with respect to the housing 20 and the second type of clutch plates 42 are non-rotatable with respect to the steering shaft 28, apart from the rotational play discussed above, friction between the clutch plates 40 and 42, when the electromagnetic coil 48 is energized, causes the stop mechanism to brake the steering apparatus18, i.e. stop rotation of the steering shaft 28 relative to the housing 20.

[0021] There is a spring 56 which preloads the clutch plates 40 and 42 for improved gap control between the clutch plates 40 and 42. The spring 56 performs two functions, namely, counteracting gravitational forces which may pull the clutch plates 40 and 42 apart and providing passive background steering resistance by partially forcing the clutch plates 40 and 42 together. The steering apparatus 18 may also be provided with a shim 58 between the electromagnetic coil 48 and the mounting plate 52. The shim 58 is a liquid shim in this example. The shim 58 sets the electromagnetic coil 48 and the mounting plate 52 apart by a predetermined clearance and which allows for consistency in the attractive force of the magnetic field.

[0022] The steering apparatus 18 further includes a circuit board 60 upon which is mounted a microcontroller 62, an H-bridge driver 64, and a rotational sensor 66. The microcontroller 62 controls current supplied to the electromagnetic coil 48 to provide dynamic steering resistance.The H-bridge driver 64 is responsible for energizing or applying current to the electromagnetic coil 48 to both vary steering resistance and brake the steering apparatus 18. The H-bridge driver 64 may also apply a reverse polarity pulse to the electromagnetic coil 48 when the steering shaft is rotated away from a hardstop. The rotational sensor 66 detects rotation of the steering shaft 28. In this example, a magnet 68 is disposed on an end of a shaft 70 of the armature 50 which rotates with the

steering shaft 28. The rotational sensor 66 detects rotation of the magnet 68 and, accordingly, rotation of the steering shaft 28 and steering wheel 16.

[0023] Dynamic steering resistance is accomplished through pulse width modulation (PWM) of current supplied to the electromagnetic coil 48. The electromagnetic coil 48 may thereby only be partially energized, resulting in some friction between the clutch plates 40 and 42 but not sufficient to friction to stop the steering shaft 28 from rotating.The amount of steering resistance can be adjusted by the microcontroller 62 for different circumstances. For example, when the steering wheel 16 and steering shaft 28 are rotated too fast or the outboard engines 12a and 12b are heavily loaded. The outboard engines may be prevented from keeping up with the steering apparatus 18. The steering resistance can then be made greater to provide feedback to the operator, slowing down the rate of rotation of the steering wheel 16 and steering shaft 28. The steering resistance can also be made greater at higher boat speeds and lower at low boat speeds as encountered during docking. Greater steering resistance can also be used to indicate that the battery charge is low to discourage fast or unnecessary movements of the steering apparatus. Steering resistance can also be made greater to provide a proactive safety feature for non-safety critical failures. By imposing a slight discomfort to the operator, this intuitive sensation feedback alerts the operator that the steering system behaves in a reduced performance steering mode, encouraging the operator to slow down the boat or return to dock. It will be appreciated that the spring 56 also provides steering resistance and, accordingly, there may be steering resistance even when the electromagnetic coil 48 is not energized. This allows for power conservation while still having steering resistance.

[0024] The microcontroller 62also drives the H-Bridge driver 64 to energize the electromagnetic coil 48 to actuate a stop mechanism 72, shown in Figure 3, to brake the steering apparatus 18, i.e. to stop rotation of the steering shaft 28. Braking occurs when the rotational sensor 66 senses that the steering shaft has reached a hardstop position based on a steering angle. The stop mechanism 72 is generally comprised of the multi-plate clutch 38, shown in Figure 2, the plates of which are urged into frictional

engagement with one another by the electromagnetic actuator to restrict rotation of the steering shaft 28. In particular, the stop mechanism 72 is actuated to fully engage the steering shaft 28 to prevent rotation of the steering shaft 28 in a first rotational direction, which corresponds to movement towards the hardstop position, while allowing rotational play between the steering shaft 28 and the stop mechanism 72 in a second direction, which corresponds to rotational to rotational movement away from the hardstop position, when the sensor senses the steering shaft has reached a hardstop position.

[0025] The H-bridge driver 64 applies a reserve polarity pulse to the electromagnetic actuator when the stop mechanism 72 is fully engaged with the steering shaft 28 and the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction.In this example, the H-bridge driver is a STMicroelectronics VNH2SP30-E but any suitable H-bridge driver may be used. As shown in Figures 4A to 4C, four switches S1, S2, S3 and S4 are integrated into the H-bridge driver 64 and are arranged as an H-bridge 74 to switch the polarity of the current going to the electromagnetic coil 48. There is a current shunt Rs, in this example, for measuring the current passing through the electromagnetic coil 48, but this is not required. In this example, the PWM to the H-bridge 74 is a signed magnitude of 20 kHz PWM. The function of the H-bridge 74 is to reduce the magnetic remanence/hysteresis effect. This results in a steering effort for a given steering PWM remaining substantially the same before and after a hardstop. In alternative examples the H-bridge 74 may have another means such as an internal current sensing sensor to measure current passing through the electromagnetic coil.

[0026] In operation, when a hardstop is reached a hardstop PWM of, for example, is +100% is applied and S2 and S3 are open while S1 and S4 are closed as shown in Figure 4A. Current flows from a 12V power source through S1 into the electromagnetic coil 48 and then through S4 to ground. When the rotational sensor 66 senses that the steering shaft 28 is being rotated away from the hardstop, as permitted by the rotational play, the microcontroller 62 drives the H-bridge driver 64 to apply a reverse polarity pulse for a fixed duration of time which is determined by the characteristics of the electromagnetic coil 48. In this example, a reverse polarity pulse is applied for approximately 15 to 20

milliseconds at a moment when steering away from the hardstop occurs. During the application of the reverse polarity pulse, S2 and S3 are closed while S1 and S4, are open as shown in Figure 4B. A reverse polarity pulse of, for example, -100% is applied. Current flows to ground through S2, electromagnetic coil 48, S3 and then back to the 12V power source. This transition from current flowing in one polarity, as shown in Figure 4A, to current flowing in the reverse polarity, as shown in Figure 4B, causes the electromagnetic coil 48 current to rapidly decay as it is flowing against the full force of the power voltage supply. As steering continues away from the hardstop there is a steering PWM of, for example +10% to +20%, and S1 and S4 are closed as shown Figure 4C. The current flows in the same direction as when the stop mechanism 72 of the steering mechanism is fully engaged but the PWM is reduced to provide a steering resistance. A reduced steering effort is accordingly required when steering away from a hardstop.

[0027] Figure 5 illustrates the H-Bridge PWM control logic when steering away from a hardstop occurs. The top graph is a steering angle versus time plot and the bottom graph is a signed magnitude PWM versus time plot. The steering shaft 28 is at a hardstop at time t_0 and a hardstop PWM is applied to electromagnetic coil 48 of the steering apparatus 18, causing the stop mechanism 72 to fully engage the steering shaft. At time t_1 the steering shaft 28 starts to rotate away from the hardstop as permitted by the rotational play. At t_2 the steering shaft has been steered an angular distance equal to a hysteresis threshold, i.e. the steering position reaches 'Hardstop – Hysteresis'. This triggers the beginning of the reverse polarity pulse logic in the microcontroller 62. The microcontroller 62 drives the H-bridge driver 64 to apply a PWM voltage to the electromagnetic coil that has a reverse polarity compared to the hardstop PWM. This quickly decays the current in the electromagnetic coil 48 and neutralizes the magnetic hysteresis effect in the electromagnetic coil 48. The reverse polarity pulse also reduces the mechanical hysteresis effect in the stop mechanism assembly. The reverse polarity pulse duration in the example is between 15 and 20ms. The reverse polarity pulse ends at time t_3 and the H-bridge driver applies a steering resistance PWM to the electromagnetic coil that has the same polarity as the hardstop PWM. The steering effort at time t_3 will

accordingly be very similar to the steering effort before the hardstop was engaged at time t_0. This is a result of the reverse polarity pulse.

[0028] Figure 6 illustrates the state diagram of the steering apparatus control logic. There are three main states, namely, a Steering State, Hardstop State, and Reverse Polarity Pulse State. In the Steering State, the microcontroller controls and varies the steering resistance by monitoring the different inputs of different sensors on the vehicle. For example, this may include inputs from the rotational sensor 66, shown in Figures 2 and 3, which functions as a steering position sensor and/or a vehicle speed sensor (not shown) to allow steering resistance to be correlated to vehicle speed, e.g. the higher the marine vessel speed, the higher the steering resistance. The logic enters the Hardstop State when the rotational sensor 66 senses a hardstop has been reached. The Hardstop State can be further defined into three sub-states. There is a Brake on PWM Sub-State which executes when the hardstop is reached and the microcontroller 62 drives the H-bridge driver 64 to apply the hardstop PWM. After a predetermined time T_2 has elapsed, one second in this example, the logic enters the Brake Hold PWM Sub-State and the microcontroller 62 drives the H-Bridge driver 64 to apply a lower PWM to the electromagnetic coil 48. The lower PWM is such that it maintains the same braking force but draws lower current. After a predetermined time T_3 has elapsed, thirty seconds in this example, the logic enters a Reduce PWM Sub-State, and the PWM is lowered further to further lower current draw and prevent the electromagnetic coil from overheating. At any given time when the Hardstop State is being executed, if the steering shaft 28 has been steered away from a hardstop and reaches a position that is equal or less than hardstop angle – hysteresis angle, the logic transitions to the Reverse Polarity Pulse State. In the Reverse Polarity Pulse State, a reverse polarity pulse is applied for a fixed duration to remove the magnetic and mechanical hysteresis effect resulting from the hardstop PWM generated during the Hardstop State. The logic enters the Steering State again after a preset reverse polarity timer T_1 elapsed.

[0029] It will be understood by a person skilled in the art that the steering mechanism discloses herein may be used any steered vehicle, for example, Figure 7 shows the steering apparatus 18 disclosed herein used to steer a land vehicle in form of a truck 76.

[0030] It will also be understood by a person skilled in the art that many of the details provided above are by way of example only, and are not intended to limit the scope of the invention which is to be determined with reference to the following claims.

What is claimed is:

1. A steering apparatus for a steered vehicle, the steering apparatus comprising:

a rotatable steering shaft;

a sensor which senses angular movement of the steering shaft as the vehicle is being steered;

a stop mechanism which releasablyengages the steering shaft to prevent rotation of the steering shaft;

an electromagnetic actuator which actuates the stop mechanism to engage or release the steering shaft;

a microcontroller which causes the electromagnetic actuator to actuate the stop mechanism to fully engage the steering shaftwhen the sensor senses that the steering shaft has reached a hardstop position to prevent rotation of the steering shaft in a first rotational direction, which corresponds to movement towards the hardstop position,while allowing rotational play between the steering shaft and the stop mechanism in a second direction, which corresponds to rotational movement away from the hardstop position;

a driver which applies a reserve polarity pulse to the electromagnetic actuator when the stop mechanism is fully engaged with the steering shaft and the steering shaft is rotated, as permitted by the rotational play, in the second rotational direction.

2. The steering apparatus as claimed in claim 1 wherein the driver applies the reserve polarity pulse to the electromagnetic actuator at a moment when the steering shaft is rotatedin the second rotational direction.

3. The steering apparatus as claimed in claims 1 or 2 wherein the microcontroller causes the electromagnetic actuator to actuate the stop mechanism to release the steering shaft when the stop mechanism is fully engaged with the steering shaft and the steering shaft is rotated, as permitted by the play, in the second rotational direction.

4. The steering apparatus as claimed in any one of claims 1 to 3 wherein the microcontroller causes the electromagnetic actuator to actuate the stop mechanism to partially engage the steering shaft to provide steering resistance.

5. The steering apparatus as claimed in any one of claims 1 to 4 wherein the stop mechanism includes a multi-plate clutch, the multi-plate clutch having a plurality of clutch plates which are urged into frictional engagement with each other by the electromagnetic actuator to engage the steering shaft.

6. The steering apparatus as claimed in any one of claims 1 to 5 further including a housing having a hollow interior, whereinthere are grooves on an interior wall of the housing and a first type of clutch plates have projections which fit within the grooveson the interior wall of the housing.

7. The steering apparatus as claimed in any one of claims 1 to 6 further including resilient, channel-shaped inserts in the grooves on the interior wall of the housing.

8. The steering apparatus as claimed in any one of claims 1 to 7 further including grooves on the steering shaft wherein a second type of clutch plates have projections which fit within the grooves in the steering shaft, the grooves on the steering shaft of the housing being wider than the projections to allow for the rotational play between the steering shaft and the stop mechanism when the stop mechanism is fully engaged.

9. The steering apparatus as claimed in any one of claims 1 to 8 further including inserts in the groovesin the steering shaft.

10. The steering apparatus as claimed in any one of claims 1 to 9 wherein the electromagnetic actuator includes a electromagnetic coil, a mounting plate and an armature, and wherein the clutch plates are disposed between the electromagnetic coil and the armature.

11. The steering apparatus as claimed in any one of claims 1 to 10 further including aspring which preloads the clutch plates for improved gap control.

12. The steering apparatus as claimed in any one of claims 1 to 11 further including a shim between the electromagnetic coil and the mounting plate to set the electromagnetic coil and the mounting plate at a predetermined clearance.

13. A vehicle provided with the steering apparatus as claimed in any one of claims 1 to 12.

14. The vehicle as claimed in any one of claims 1 to 12 wherein the vehicle is a marine vessel.

15. The vehicle as claimed in claim 1 in any one of claims 1 to 12 wherein the vehicle is a land vehicle.

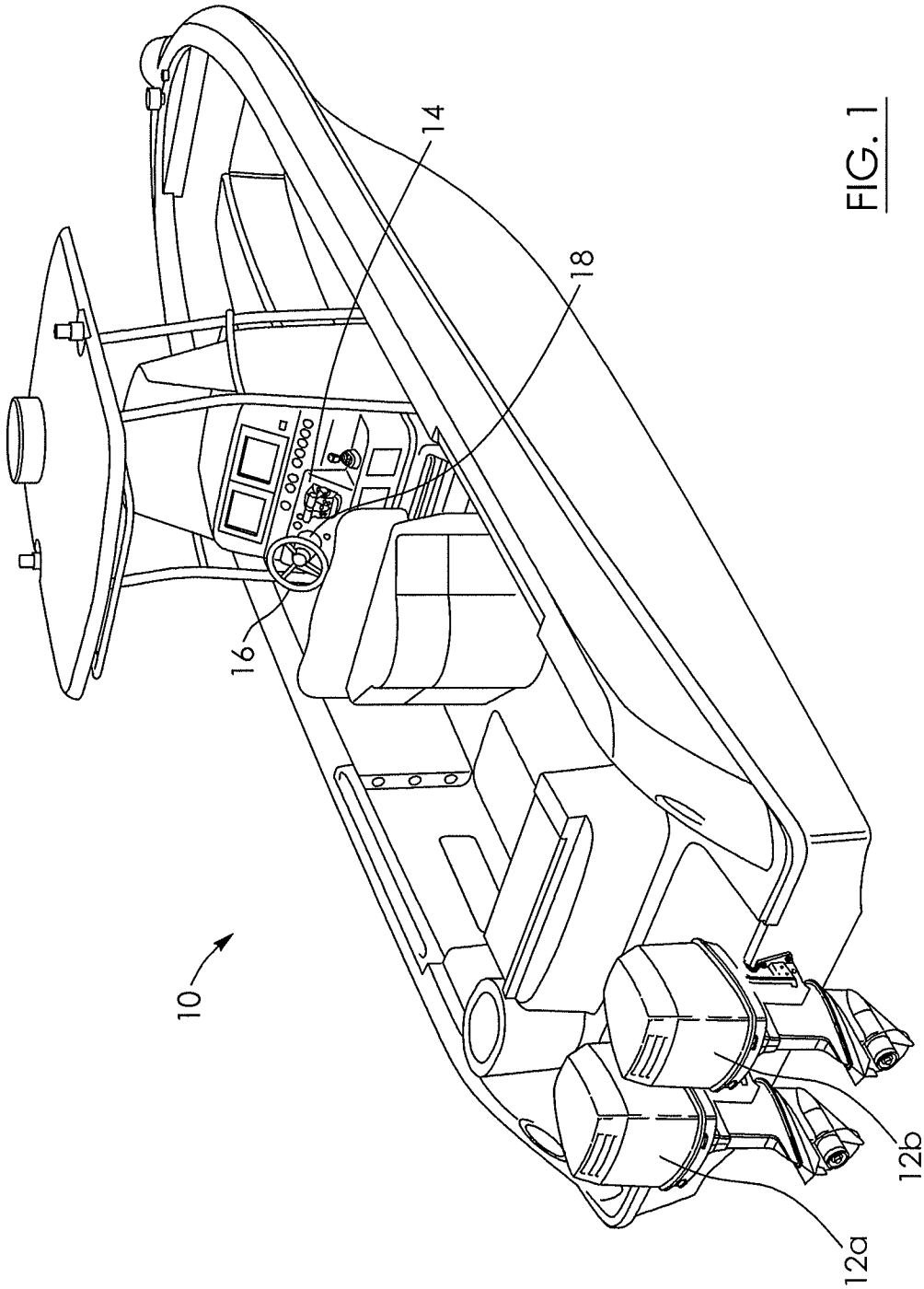

FIG. 1

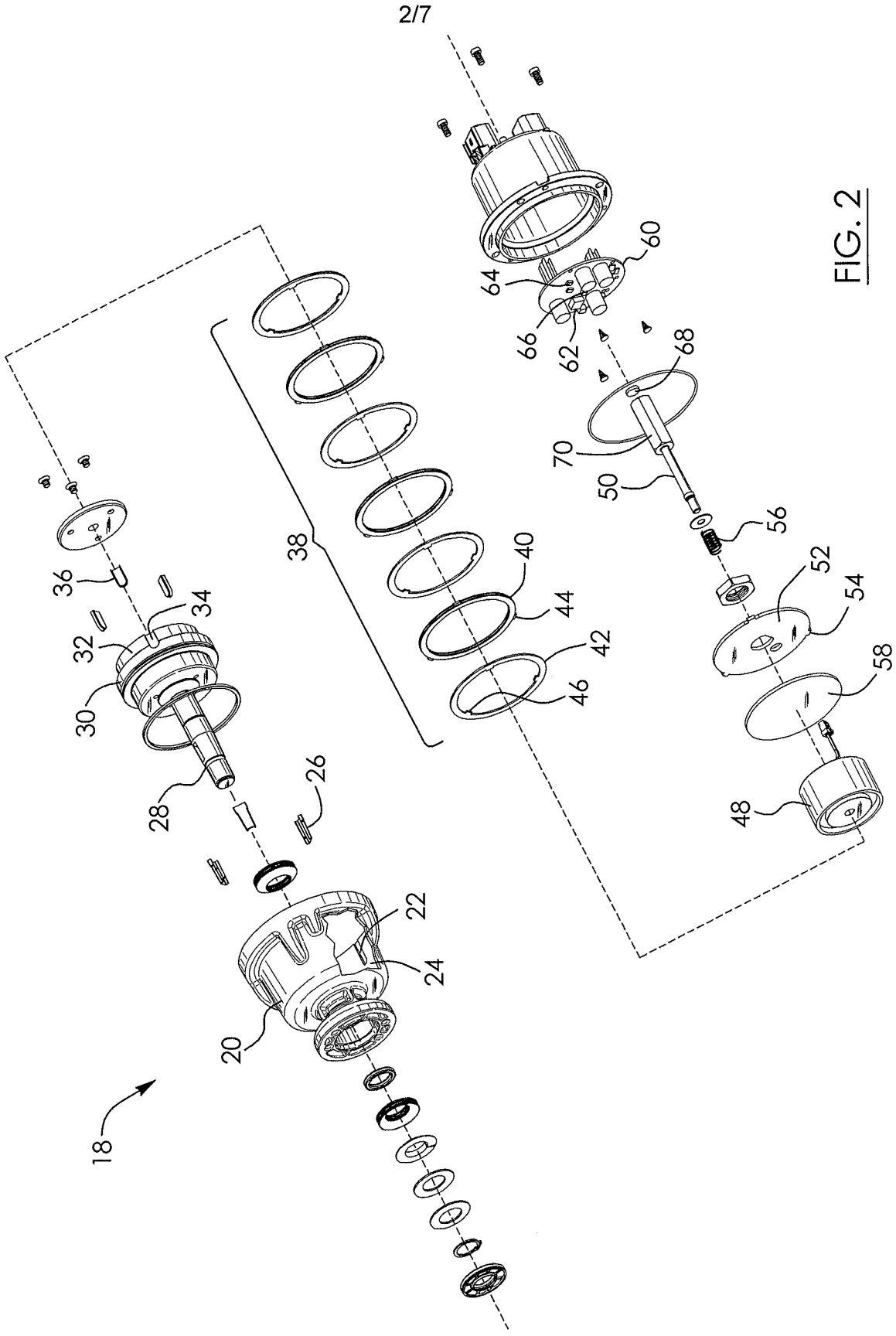
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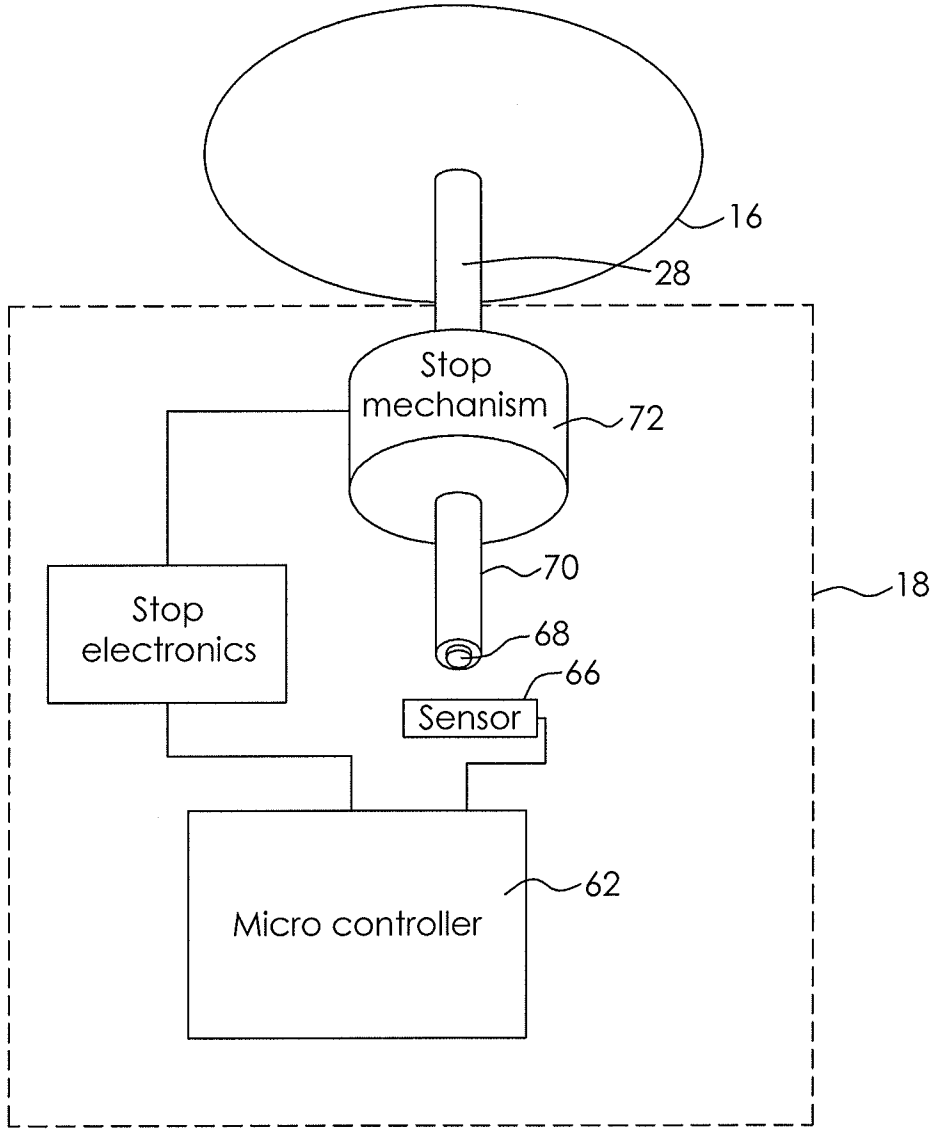
FIG. 2


16
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Stop mechanism
72
70
18
Stop electronics
68
66
Sensor
62
Micro controller

FIG. 3

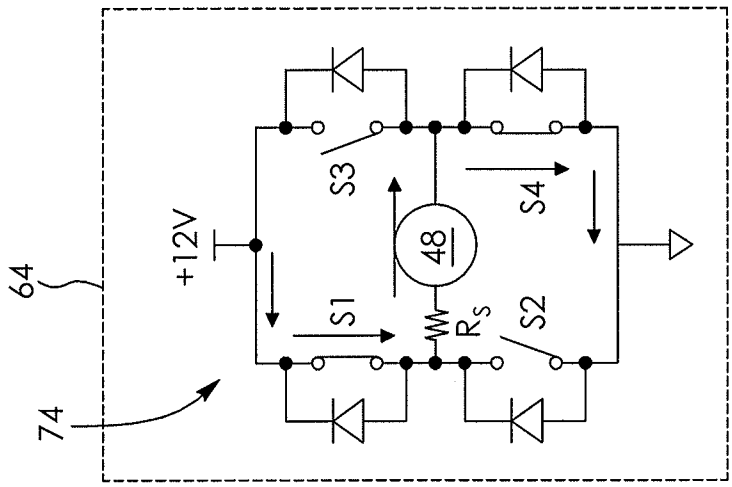

FIG. 4C

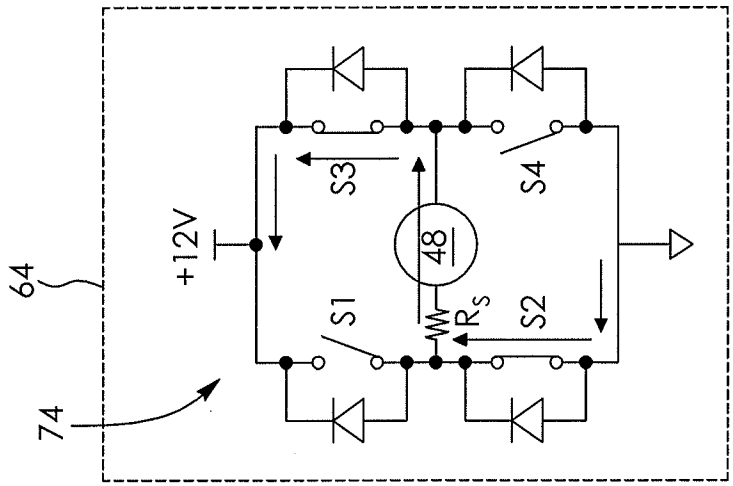

FIG. 4B

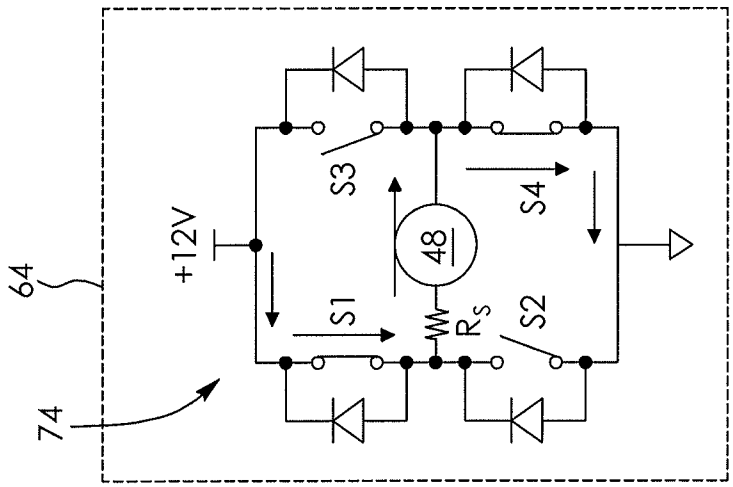

FIG. 4A

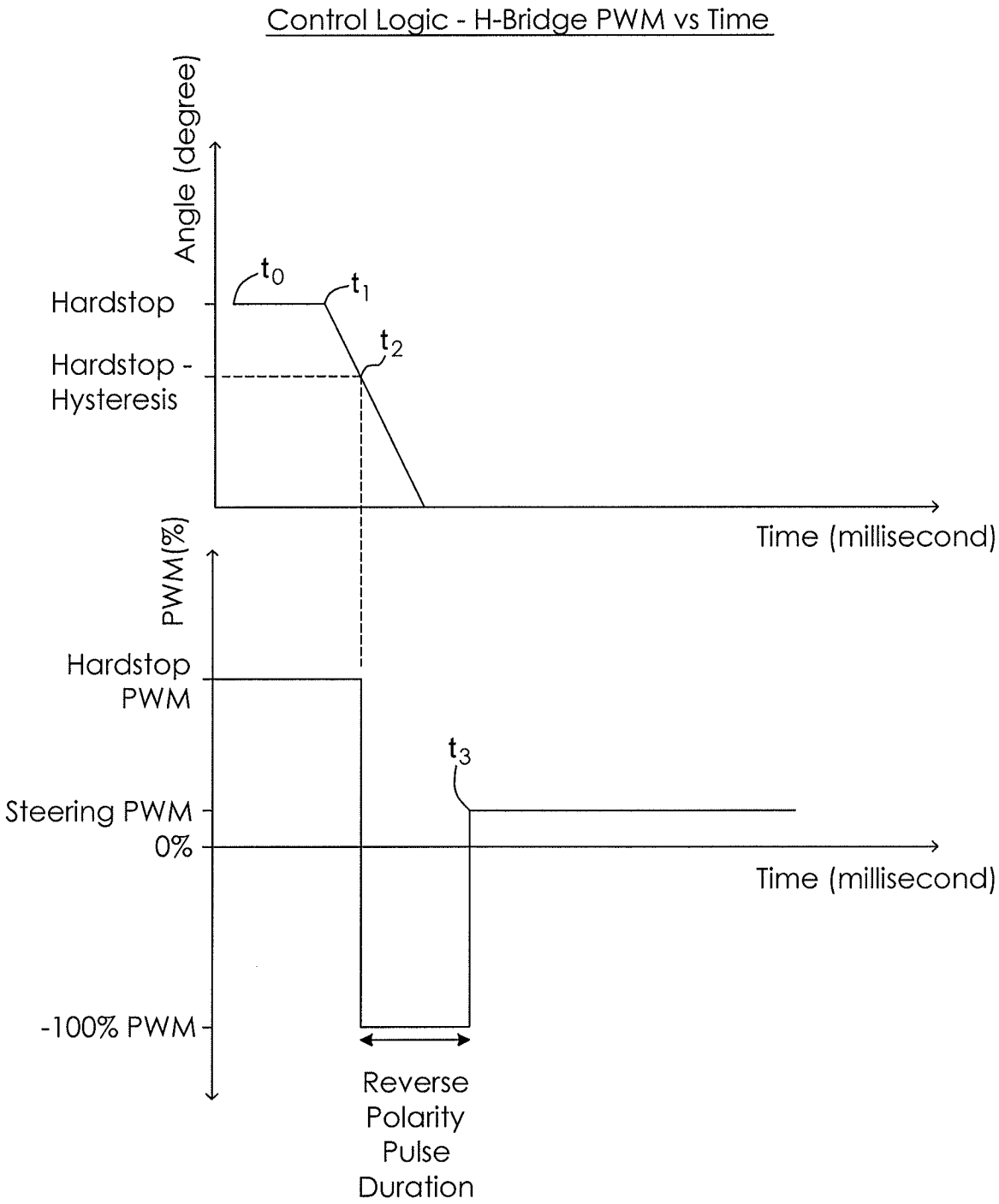
Control Logic - H-Bridge PWM vs Time
Angle (degree)
Hardstop
Hardstop - Hysteresis
t_0
t_1
t_2
Time (millisecond)
PWM(%)
Hardstop PWM
t_3
Steering PWM 0%
Time (millisecond)
-100% PWM
Reverse Polarity Pulse Duration

FIG. 5

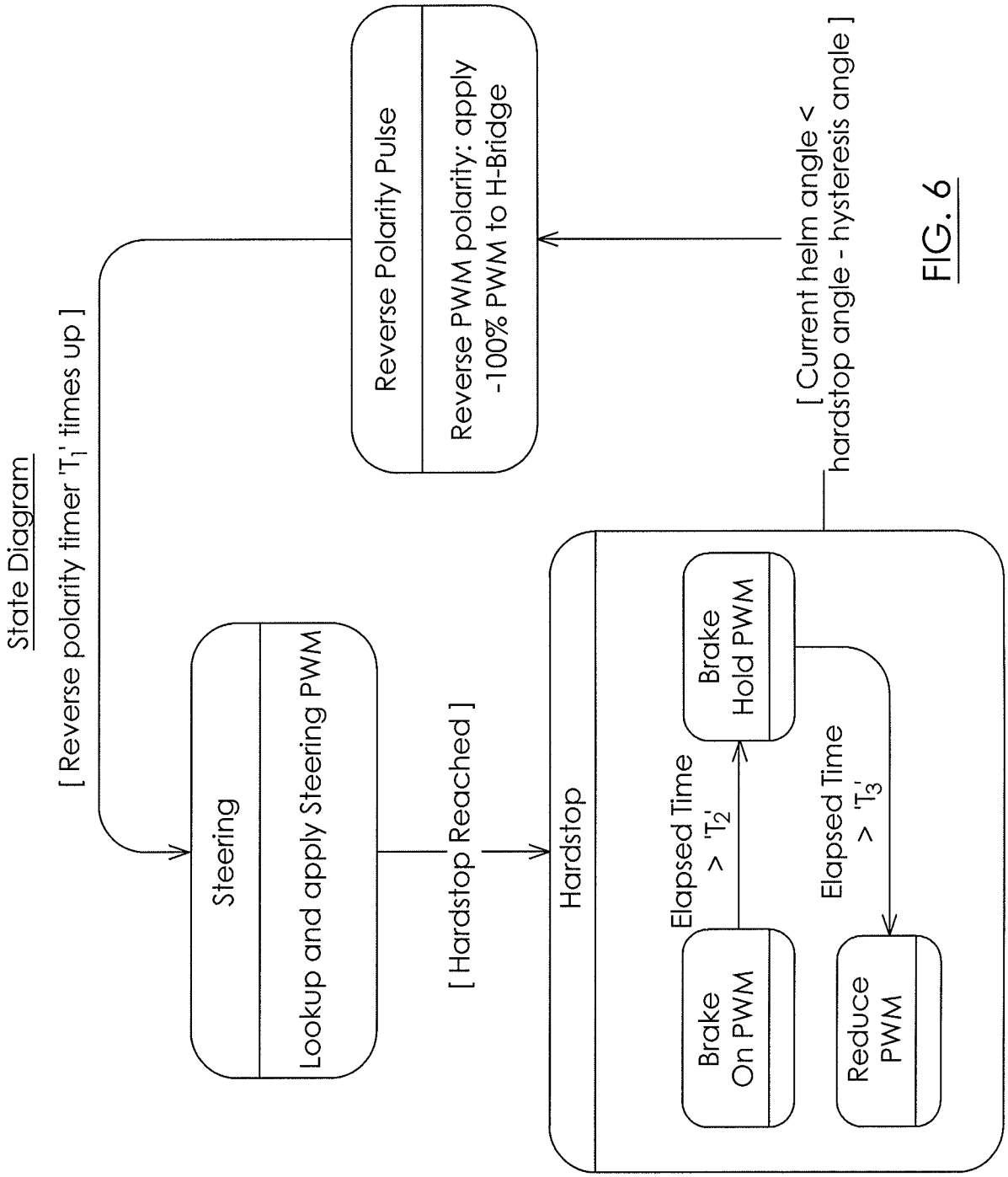
State Diagram
[Reverse polarity timer 'T1' times up]
Steering
Lookup and apply Steering PWM
[Hardstop Reached]
Hardstop
Brake
On PWM
Elapsed Time
> 'T2'
Brake
Hold PWM
Elapsed Time
> 'T3'
Reduce
PWM
[Current helm angle <
hardstop angle - hysteresis angle]
Reverse Polarity Pulse
Reverse PWM polarity: apply
-100% PWM to H-Bridge

FIG. 6

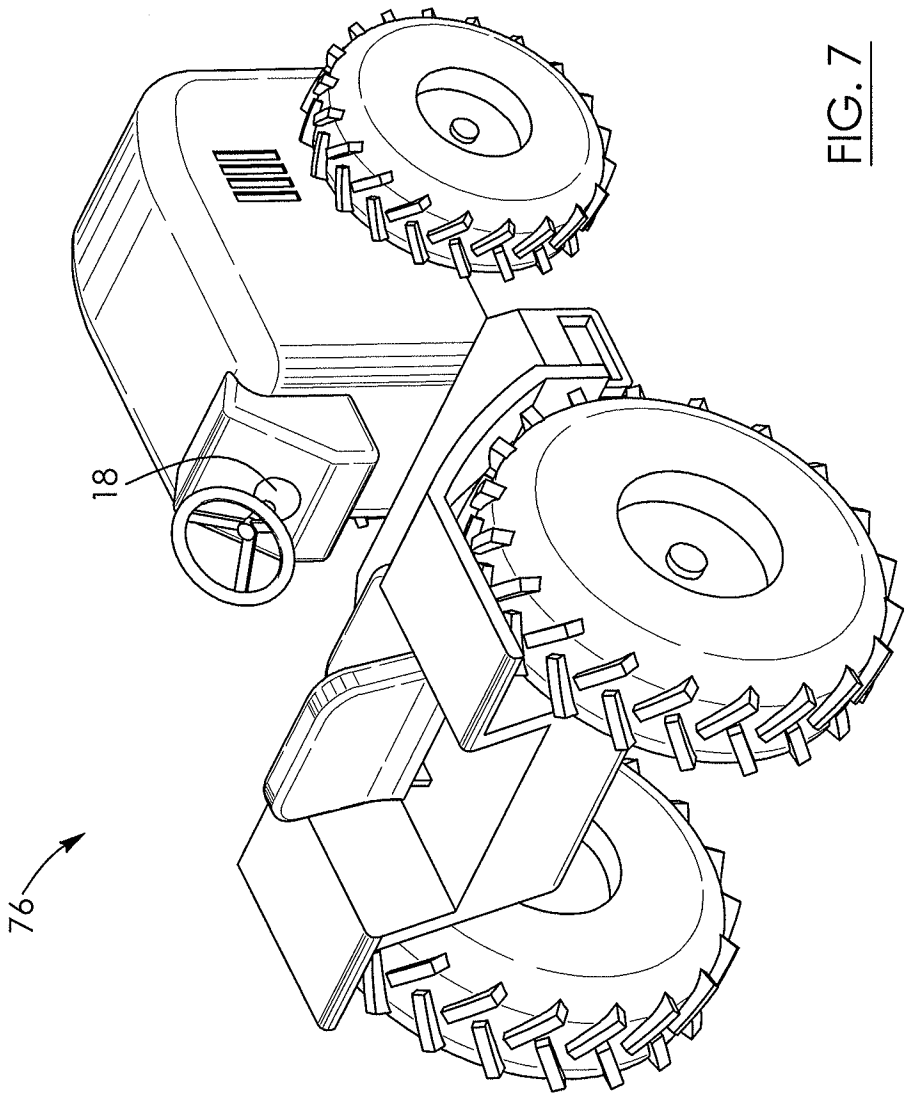

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/026142

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B63H 25/24 (2013.01)
USPC - 114/170
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B63H 25/00, 25/14, 25/18, 25/24 (2013.01)
USPC - 114/144A, 144R, 162, 170

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B63H 25/00, 25/14, 25/18, 25/24

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patent Search, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/0229834 A1 (WONG et al) 20 October 2005 (20.10.2005) entire document	1-3
Y	US 2006/0042532 A1 (WONG et al) 02 March 2006 (02.03.2006) entire document	1-3
A	US 7,258,072 B2 (WONG et al) 21 August 2007 (21.08.2007) entire document	1-3
A	US 2011/0195816 A1 (MARTIN et al) 11 August 2011 (11.08.2011) entire document	1-3

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 March 2013	05 APR 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/026142

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-15
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.