Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2800792 C 2016/10/25

(11)(21) **2 800 792**

(12) BREVET CANADIEN / CANADIAN PATENT

(13) **C**

(22) **Date de dépôt/Filing Date:** 2013/01/04

(41) **Mise à la disp. pub./Open to Public Insp.:** 2013/07/06

(45) **Date de délivrance/Issue Date:** 2016/10/25

(30) **Priorité/Priority:** 2012/01/06 (US61/583,846)

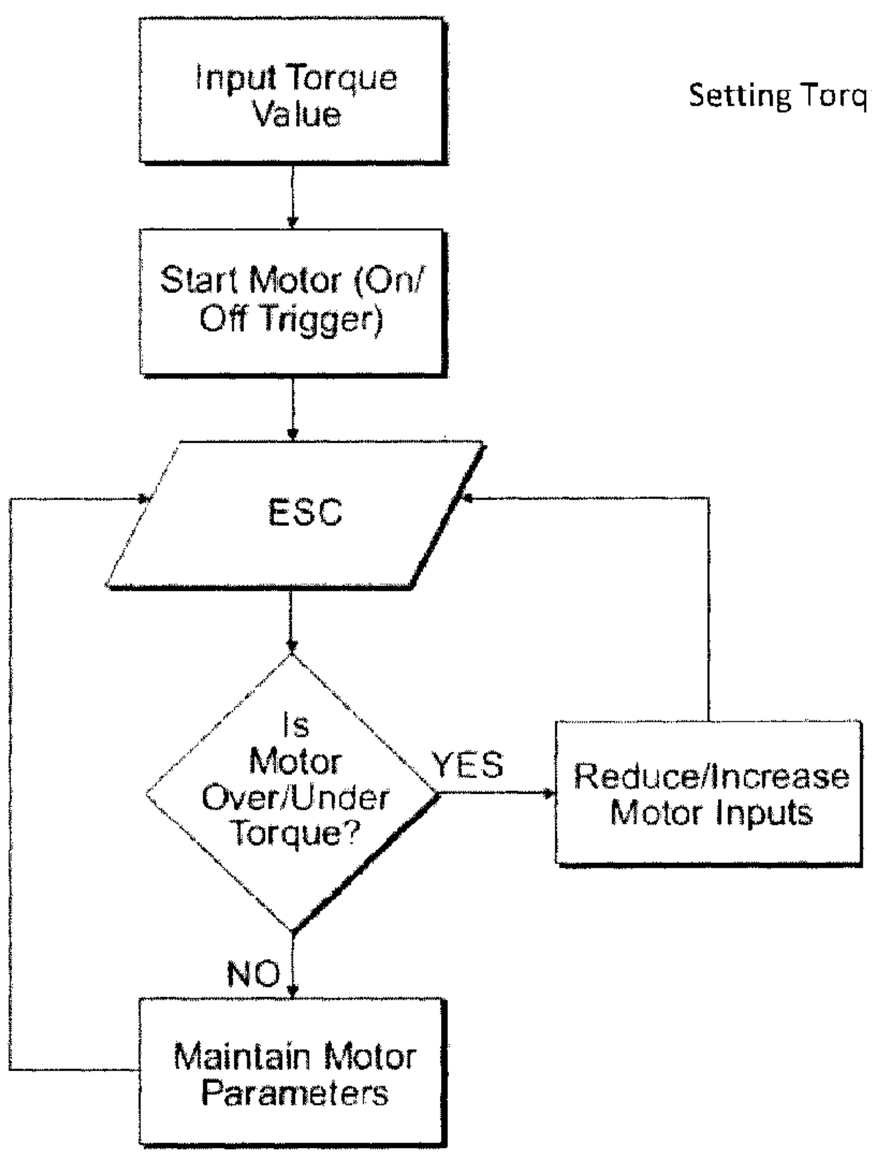
(51) **Cl.Int./Int.Cl.** ***B25F 5/00*** (2006.01), ***H02J 7/00*** (2006.01), ***H02P 6/08*** (2016.01)

(72) **Inventeurs/Inventors:**
KNIGHT, COLIN, US;
CORIC, MILOS, US

(73) **Propriétaire/Owner:**
SEARS BRANDS, LLC, US

(74) **Agent:** NORTON ROSE FULBRIGHT CANADA LLP/S.E.N.C.R.L., S.R.L.

(54) **Titre : OUTIL ELECTRIQUE PORTATIF PROGRAMMABLE AVEC MOTEUR CC SANS BALAIS**
(54) **Title: PROGRAMMABLE PORTABLE POWER TOOL WITH BRUSHLESS DC MOTOR**



(57) **Abrégé/Abstract:**
A power tool that includes a brushless DC motor, one or more motor sensors, and a controller, such as, for example, an electronic speed control (ESC) circuit. The controller is adapted to provide instructions to control the operation of one or more parameters of the brushless DC motor. The controller is also adapted to receive feedback from one or more motor sensors that reflect whether the motor is attaining the one or more parameters. The controller may also be adapted to have a learning mode, in which feedback provided during use of the power tool is stored by the controller as a program so that the same operating parameters may be subsequently replicated by using the program to operate the tool. The controller may also use the feedback to adjust the operation of the motor so that the motor maintains one or more selected or programmed operating parameters.

ABSTRACT

A power tool that includes a brushless DC motor, one or more motor sensors, and a controller, such as, for example, an electronic speed control (ESC) circuit. The controller is adapted to provide instructions to control the operation of one or more parameters of the brushless DC motor. The controller is also adapted to receive feedback from one or more motor sensors that reflect whether the motor is attaining the one or more parameters. The controller may also be adapted to have a learning mode, in which feedback provided during use of the power tool is stored by the controller as a program so that the same operating parameters may be subsequently replicated by using the program to operate the tool. The controller may also use the feedback to adjust the operation of the motor so that the motor maintains one or more selected or programmed operating parameters.

PROGRAMMABLE PORTABLE POWER TOOL WITH BRUSHLESS DC MOTOR

Field of the Disclosure

The present description relates generally to portable power tools and more particularly to a programmable portable power tool with a brushless DC motor.

Brief Description Of The Drawings

Figure 1 illustrates a flow chart for setting a torque parameter for a brushless DC motor for a power tool according to certain embodiments of the present invention.

Figure 2 illustrates a flow chart for setting a speed parameter for a brushless DC motor for a power tool according to certain embodiments of the present invention.

Figure 3 illustrates a flow chart of a learning mode for a controller used with a brushless DC motor for a power tool according to certain embodiments of the present invention.

Figure 4 illustrates a flow chart for operating a brushless DC motor for a power tool using a program stored in a controller according to certain embodiments of the present invention.

Figure 5 illustrates a flow chart for operating a brushless DC motor for a power tool in which a tapping program is created by the user and executed by a controller according to certain embodiments of the present invention.

Figure 6 illustrates a flow chart for downloading information to a controller used with a brushless DC motor for a power tool according to certain embodiments of the present invention.

Detailed Description

The following description of example methods and apparatus is not intended to limit the scope of the description to the precise form or forms detailed herein. Instead the following description is intended to be illustrative so that others may follow its teachings.

The present disclosure relates to a new range of portable power tools. Some of the example tools use brushless DC motor technology, and in some examples the brushless DC motor technology will include out-runner brushless motors. The present disclosure utilizes brushless technology to provide various user features and benefits that were previously not available and enhance some of the power tool performance characteristics.

Brushless DC motors are inherently intelligent due to their ESC (Electronic Speed Control) which is required to operate them. By utilizing the ESC intelligence one input, various advances features and/or benefits are disclosed herein. In one example, the features and benefits described herein are especially well suited for battery powered drill drivers.

For instance, in one example, the battery powered tool may include any suitable battery including a Lithium-based battery such as a lithium ferrite battery. In one example, the battery may be stackable and/or otherwise expandable to met the power tool needs. For instance, the battery may be an accordion-style (or other style) removable battery with multiple cells insertable into the tool to add and/or subtract battery power as needed.

In regard to the motor, the present disclosure utilizes a brushless DC motor, such as for instance, a brushless outrunner motor to provide motion to the power tool. This type of brushless motor spins its outer shell around its windings, and the stationary (stator) windings of the outrunner

motor are excited by conventional DC brushless motor controllers. A direct current (switched on and off at high frequency for voltage modulation) is typically passed through three or more non-adjacent windings together, and the group so energized is alternated electronically based upon rotor position feedback. Because the motor relies upon a motor controller, the information contained within the controller can be utilzed by the present disclosure to enhance various features of the disclosed power tool.

In particular, the present disclosure has a number of features and/or benefits described in further detail below. In various examples the present power tool is capable of being programmed to monitor, display, and/or control torque, speed, and/or revolutions per minute (rpm), and/or provide sopping, reversing, and/or partial revolutions as desired. Additionally, the power tool may provide a strobe lighting effect to provide an illusion that the tool is stationary (with safety features) thereby allowing better vision of the tool path/location.

In another example, the power tool is programmable such that a specific program such as, for example, a drilling/tapping program can be downloaded, learned, uploaded, and/or otherwise provided to the tool. The programmable content may also include software/firmware updates, usage information, user feedback, etc. The programmable content may be provided through the use of any suitable connectivity medium including, for instance, Bluetooth, wireless, IR, USB, etc. As noted, the tool may be provided with a learn mode that can learn and/or provide a program to the tool such that the tool may adapt to various usage scenarios.

In particular, in one example, the disclosed power tool my utilize the ESC with motor feedback to provide an display, such as an LCD display to show the current state of the motor's RPM and Torque. Additionally, the tool may provide for a user input via an electronic control (e.g., a touch

pad, display, or other suitable input device) to allow the user is able to "set" the desired maximum torque. The example tool is capable of utilizing the "set" parameter so that when the tool reaches this maximum setting (e.g., torque) the tool will stop and/or otherwise alter the tools rotation. In some examples, the ability to stop the tool's rotation when a maximum torque setting is reached allows for the removal of a mechanical clutch, thereby saving cost and/or wear over a traditional mechanical clutch.

Similarly, in setting the RPM parameter, a user input via electronic control allows the user to able to "set' the desired RPM value. The drill driver would be able to be `set' so that the drill will maintain a constant RPM independent of the trigger input from the user and independent of the torque load. Therefore the ESC controls the motor, thus monitoring, maintaining, and/or controlling the RPM. It will be understood that there may be a tolerance to the RPM setting and reaction time for the ESC and motor to account for various factors including environmental issues, etc.

In regard to the strobe capability, the example tool includes a synchronized strobe light, such as for instance an LED, or other suitable strobe. In one example, the strobe light is integral to the tool while in other instances, the strobe may be externally controlled and/or synchronized to the tool through any suitable means. Specifically, in one implementation, the strobe is turned on momentarily on each revolution or multiple of complete revolutions, and turned off the remaining portion of the revolution. This on/off functionality allows the tool to `appear' stationary.

In order to better control the strobe effect, the example tool is capable to be programmed such that the strobe will turn on and off at different multiples depending upon the revolution of the

tool. This feature allows the tool to avoid certain frequencies that are too fast for the user to see and also avoid certain health related frequencies know to be detrimental to certain people. In one example implementation, the strobe frequencies may be pre-set (e.g. nonadjustable) and/or may be adjustable by the user as desired.

In regard to the programmability of the tool, in one example, the tool may include the ability to upload/download programming. For instance, the tool may be provided with different parameters and/or programs to control the motor through the ESC. These programs can be `uploaded' and/or otherwise provided to the ESC. In particular, certain parameters and/or programs such as motor braking, a fixed rpm, etc. can be sent to the tool. The communication protocols of these parameters and/or programs to the drill can be any suitable format, including USB, Bluetooth, OC, mobile device, etc.

Using the chosen program, the tool may is capable of controlling the motor and following the specified program. In one chosen program, a multi-directional program may include partial revolutions. In one illustration, a tapping may be provided which may be capable of turning in a first direction for a predetermined revolution, and then reversing into a second direction for second predetermined revolution. In one pattern, the tool may proceed forward for a revolution and then reversing a partial revolution to break the 'chips' oftentimes associated with tool drilling. This process can be repeated to the desired depth. (e.g. 15.5 revolutions in total to the bottom of a hole)

In another example program, the tool may revolve forward and reverse a determined number of revolutions. This example may be well suited for tightening a nut to a position on a shaft, or a screw (of know thread pitch) to go to a desired depth. To avoid possible issues with regard to

revolution prior to insertion of the shaft, etc., in one example, the ESC only starts counting revolutions once it has sensed the initial torque. As noted , this avoids the ESC counting any revolutions that may happen before the screw / nut has contacted the work piece.

In other embodiment, the ESC is provided with feedback from the motor (rpm and/or torque, etc.) and/or the user input (trigger setting) and is provided with a memory to record and/or otherwise store these parameters. In this way, the tool is capable of storing and/or learning the method in which the user uses the power tool. Thus, the user uses the tool whilst in `learn mode' and the ESC remembers and/or stores these parameters so that at a later time these can be reproduced without the user having to provide additional input. Upon recall of a program (possibly by a single trigger on / off input) the user simply starts the program and the ESC commands the motor to match RPM, torque and/or revolutions as 'learned'.

In yet another embodiment, a pressure sensitive trigger input is provided. In this instance, the use of pressure sensitive switch technology controls the drill driver via the ESC. Specifically, the tool is able to increase pressure on the switch and allow the ESC to increase the torque and or RPM.

In still other examples, the tool may be provided with a pressure sensitive input and/or an output control panel. In still other embodiments, the tool is provided with a waterproof / water-resistant housing to a certain depth. In this instance, the tool is provided with a heat exchange to allow excess heat to be removed from he tool, thus preventing overuse/overheating.

As noted above, the example electronic control unit may be utilized in various capacities to allow for programming of the power tool. For instance, the control may be utilized to control torque (setting and limit), to control speed (RPM), to control the number of revolutions, to control the

motor and/or tool direction, to control the position of the motor shaft, to control the time the motor is one, and/or to control any other desirable parameter. The programmability of the tool will allow for manual (user) setting or configurations, will allow for preprogrammed settings, allow for importing settings and/or apps via data ports, wireless, Bluetooth, etc., and/or may allow for the recordation, storage, and recall of settings, profiles, and/or action that the tool has performed.

In addition to the previous features, the example power tool may also include a touch sensitive control such as a multi-zoned programmable pressure sensitive trigger. In this instance, the trigger may be able to identify the degree and location of pressure to control and/or provide input to various functions/modes of the tool. In some examples, the control may configure the electronic clutch, configure the depth (e.g., for a power drill, circular saw, etc.), may program the length of stroke (e.g., for a jig saw, reciprocating saw, etc.), and/or may control the speed among other controllable features.

The tool may be constructed of an alloy construction. The tool may be manufactured utilizing a Thixomolded process, and may include a recyclable housing.

Brushless Torque Sensing

In one example, using the intelligent Brushless DC Motor (with or without Hall sensors and Electronic Speed Control Unit ESC) the ESC unit can calculate RPM and with current sensing calculates 'watts' of power which when placed in a formula with RPM allows the calculation of torque.

$$\text{Power (Watts)} = \text{Torque} \times 2\pi \times \text{RPM}/60$$

The intelligence can potentially be used for display, and setting of torque. Therefore the mechanical clutch mechanism can be removed if desired, improving reliability, accuracy and costs. For instance, if the power tool is a drill driver, the unit can be used as a torque wrench due to the accuracy of the torque sensing. This feture allows the tool the capability of being able to `set' the torque based on the electronic feedback from the motor, and also to allow the unit to display any measurements.

The torque sensing application could be used in the following (any tool with an electric motor), such as a drill driver, impact driver, router, miter saw, table saw, drill, lathe, mill, etc.

A flow chart illustrating one example torque setting methodology is illustrated in Figure 1.

Brushless DC Controlled RPM

Using the intelligent Brushless DC Motor (with or without Hall sensors and Electronic Speed Control Unit ESC) the ESC unit can either maintain constant speed (RPM) or vary it in a predetermined way (program). For example, the intelligence may be used for maintaining constant or variable RPM in portable power tools. Therefore the intelligent motor-controller system is used to improve productivity and alleviate user stress in performing tasks requiring high repeatability. If used with a mechanical positioning system, the power tool can perform similar to a CNC machine.

While using power tools in certain applications, there is a need to maintain constant speed (RPM). Examples are polishing (buffing) a car or performing a tapping operation with a drill/driver held in a vertical slide acting as a drill press. In both applications constant RPM is required and the load on the tool may vary (pressing a buffing compound a bit harder against car

surfaces, will increase load (torque) and slow the tool down, thus causing varying quality of the polishing). Having a means of controlling RPM in portable power tools solves this problem.

When performing a task that requires constant or controlled varying in RPM, an user sets a desired constant RPM, using a graphic user interface. If preprogrammed variable RPM is desired user will either program it using "learning mode" or download existing program. For constant RPM, set desired RPM on the drill/driver. For variable RPM, perform one operation manually varying speed and power. Finish data collecting. Save the program. Call program. Execute the program required number of times.

A flow chart illustrating one example RPM setting and downloading of data is illustrated in Figures 2 and 6.

Brushless DC learning mode

As with the previous features, using the intelligent Brushless DC Motor (with or without Hall sensors and Electronic Speed Control Unit ESC) the ESC unit can collect data from previous runs/usages store it, organize it and execute as a program/executable file. This will allow for the intelligence to be used for programming or executing a program in portable power tools. Therefore the intelligent motor-controller system can be used to improve productivity and alleviate user stress in performing tasks requiring high repeatability.

This will allow for a tool, such as a drill driver be able to learn, store, organize and execute a program thus increasing users productivity and alleviating user work load stemming from performing repeatable tasks. When performing a task that needs to be repeated certain number or times an user can set the drill driver to a "learn mode"; perform one complete task with drill

driver in manual mode.; finish the task store "learned" routine; and than execute it required number of times.

In one example, a drilling tool can be utilized to drill through multiple materials requiring different speed and torque. In this instance, the user can perform the steps of: Set drill to "learn mode; Perform one operation manually varying speed and power while drilling through deck board and than through deck frame; Finish data collecting; Save program; Call program; and Execute program required number of times.

A flow chart illustrating one example learn mode is disclosed in Figure 3.

Motor Control

Using the intelligent Brushless DC Motor (with or without Hal sensors and Electronic Speed Control Unit ESC) the ESC unit can calculate the position of the motor at any point during each revolution. It can also start and stop at key points in either direction (e.g., clock-wise (CW) or counter-clockwise (CCW)). This feature allows the intelligence to be used to perform multi directional actions with accuracy to stop and start during a partial and/or complete revolution.

The motor and ESC can be 'told' where to stop, start and how far to rotate. This allows the user to select a 'program' where the motor could forward and reverse at set intervals and amounts of travel / revolution. These forward and reverse intervals in multiple combinations could be a 'program', and thus tapping is one of the tools abilities.

In the example where the tool is a drill, drill drivers today cannot stop and start accurately and then continue motion to a desired amount (e.g 12.7 revolutions CW, then 10.4 CCW). In this example, tapping can be completed by turning forward 1 revolution and the reversing 1/3 of a

revolution to break the 'chips'. This process should be repeated to the desired depth. (eg 15.5 revolutions in total to the bottom of a hole)

A flow chart illustrating one example method of reversing and/or tapping a tool is disclosed in Figures 4-5.

Strobe

Sill further, by using the intelligent Brushless DC Motor (with or without Hal sensors and Electronic Speed Control Unit ESC) the ESC unit can calculate the position of the motor at any point during each revolution, and this feature allows the intelligence to be used to turn off and on a strobe light. For example, if the strobe comes on once per revolution, the drill bit or tool would appear to be stationary, therefore giving an easy view for the user to confirm accuracy of the work (cutting, driving etc.). The dust and debris would also appear stationary. By varying the strobe effect, different views of the working tool may be achieved.

CLAIMS:

1. A power tool for use by a user comprising:

a brushless DC motor;

one or more motor sensors;

a controller having a processor and a memory, the controller adapted to:

monitor both a number of clockwise and a number of counterclockwise rotations of a rotor of the brushless DC motor based at least in part on feedback from the one or more motor sensors;

reverse the direction of the rotor after the rotor has completed a predetermined number of the number of clockwise rotations; and

reverse the direction of the rotor after the rotor has completed a predetermined number of the number of counter-clockwise rotations.

2. The power tool of claim 1, wherein the controller is further adapted to determine a rotational position of a rotor of the brushless DC motor.

3. The power tool of claim 2, wherein the power tool further includes a strobe light, the strobe light operably connected to the controller, the controller being further adapted to activate and deactivate the strobe light based on the determined rotational position of the rotor.

4. The power tool of claim 1, wherein the controller is further adapted to:

receive feedback from one or more motor sensors that reflect whether the motor is operating at or within one or more parameters; and

adjust the operation of the brushless DC motor based on the received feedback so that the brushless DC motor operates at or within the one or more parameters.

5. The power tool of claim 4, wherein the power tool includes a secondary input configured to receive data for the controller from an external source.

6. The power tool of claim 4, wherein the power tool further includes:

a user input operably connected to the controller and configured to receive an indication of instructions,

a controller interface operably connected to the controller and configured to receive the one or more parameters, and

a display operably connected to the controller and configured to display information pertaining to at least one of the one or more parameters and the operation of the brushless DC motor.

7. The power tool of claim 6, wherein the controller is further adapted to:

record on the memory the received feedback provided from the one or more motor sensors;

store the recorded feedback on the memory as a program; and

execute the program to replicate the operating conditions of the brushless DC motor associated with the feedback provided by the one or more motor sensors.

8. The power tool of claim 7, wherein the controller is further adapted to begin to record the feedback on the memory when the user engages the user input.

9 The power tool of claim 7, wherein the controller interface is configured to allow the user to select a program for operation of the tool from a plurality of programs stored on the memory.

10. The power tool of claim 6, wherein the one or more parameters includes at least one of: a motor torque and a motor speed.

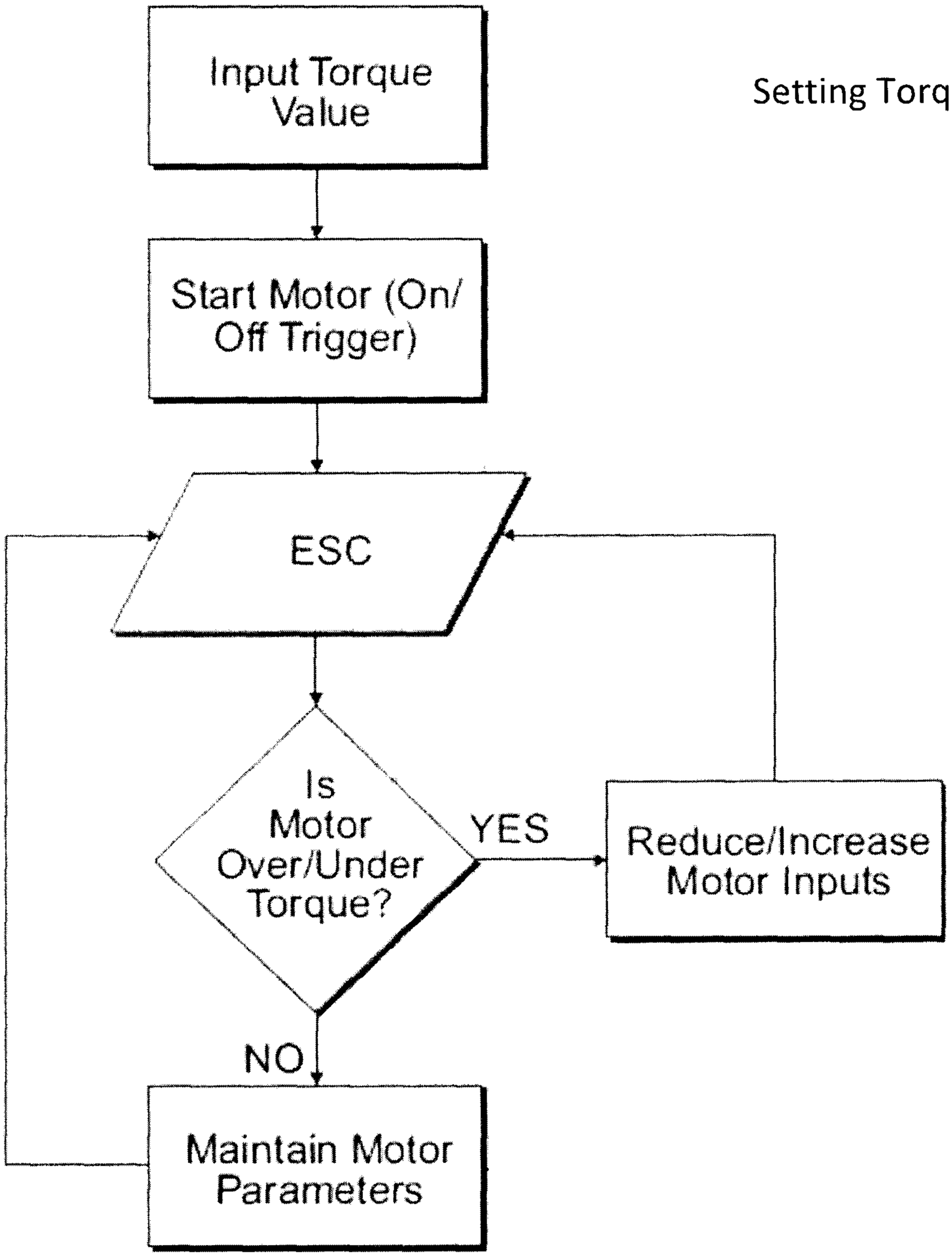

Setting Torque
Input Torque Value
Start Motor (On/ Off Trigger)
ESC
Is Motor Over/Under Torque?
YES
Reduce/Increase Motor Inputs
NO
Maintain Motor Parameters

FIG. 1

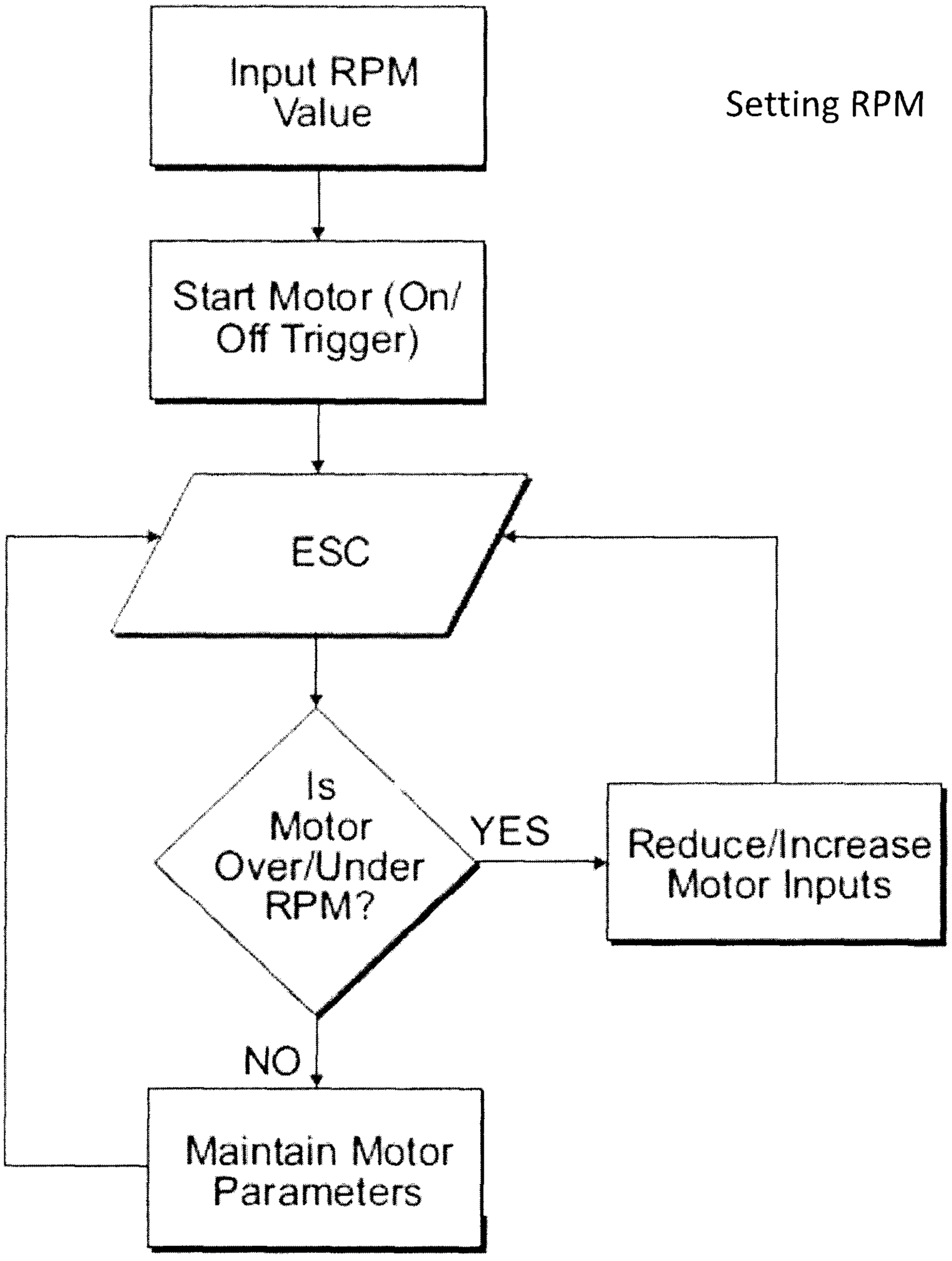

Input RPM Value
Setting RPM
Start Motor (On/ Off Trigger)
ESC
Is Motor Over/Under RPM?
YES
Reduce/Increase Motor Inputs
NO
Maintain Motor Parameters

FIG. 2

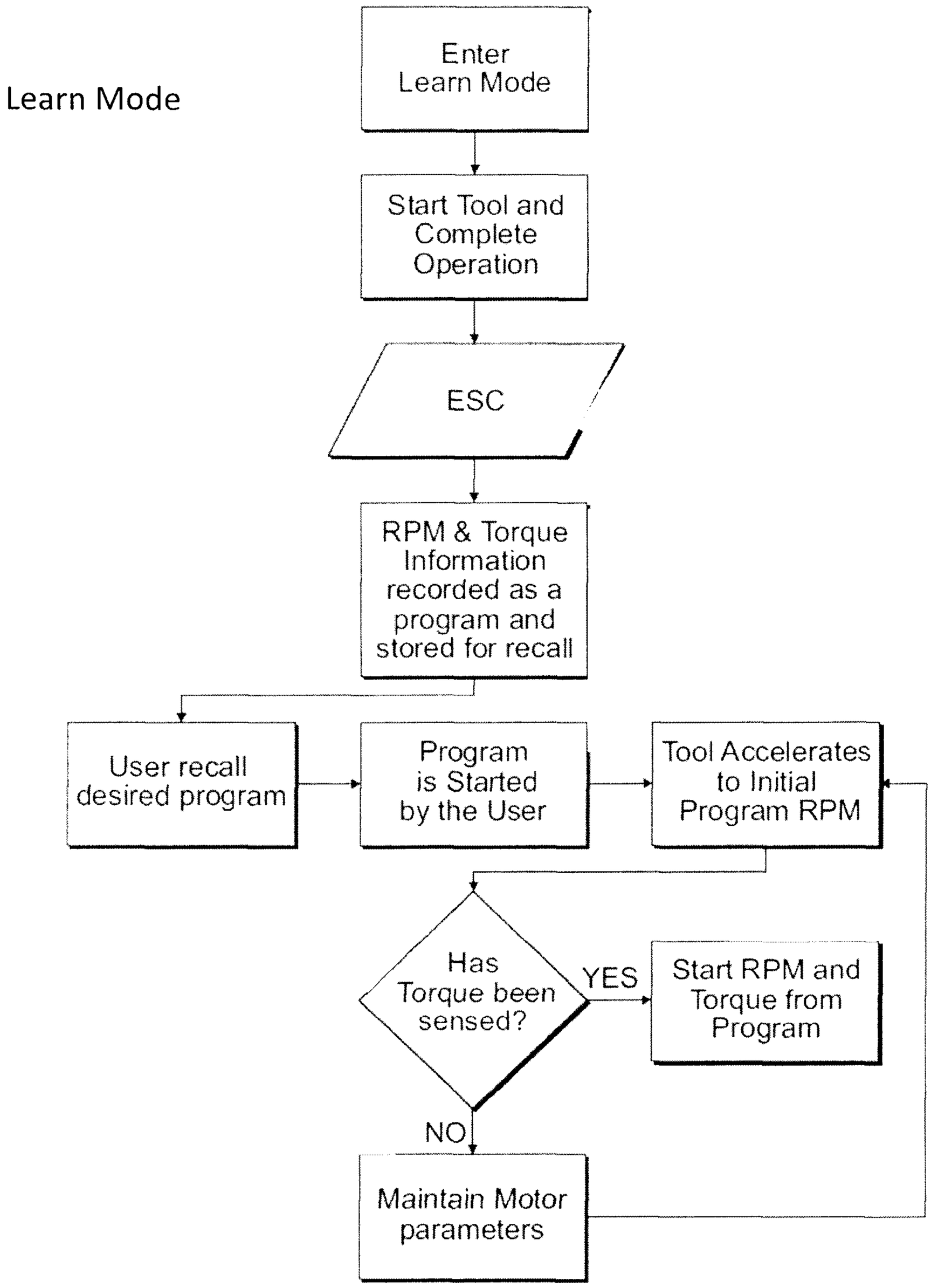

Learn Mode
Enter Learn Mode
Start Tool and Complete Operation
ESC
RPM & Torque Information recorded as a program and stored for recall
User recall desired program
Program is Started by the User
Tool Accelerates to Initial Program RPM
Has Torque been sensed?
YES
Start RPM and Torque from Program
NO
Maintain Motor parameters

FIG. 3

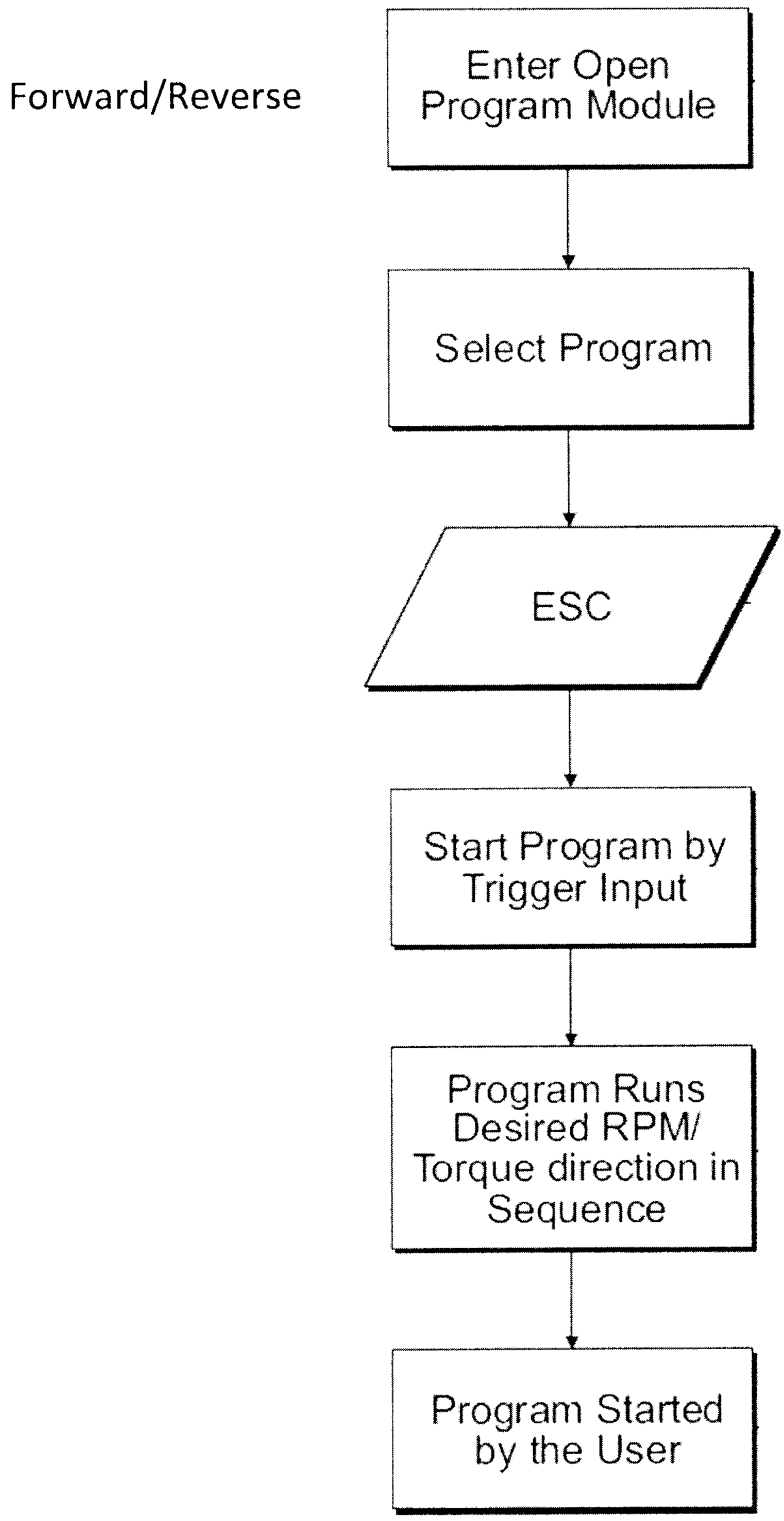

Forward/Reverse
Enter Open Program Module
Select Program
ESC
Start Program by Trigger Input
Program Runs Desired RPM/ Torque direction in Sequence
Program Started by the User

FIG. 4

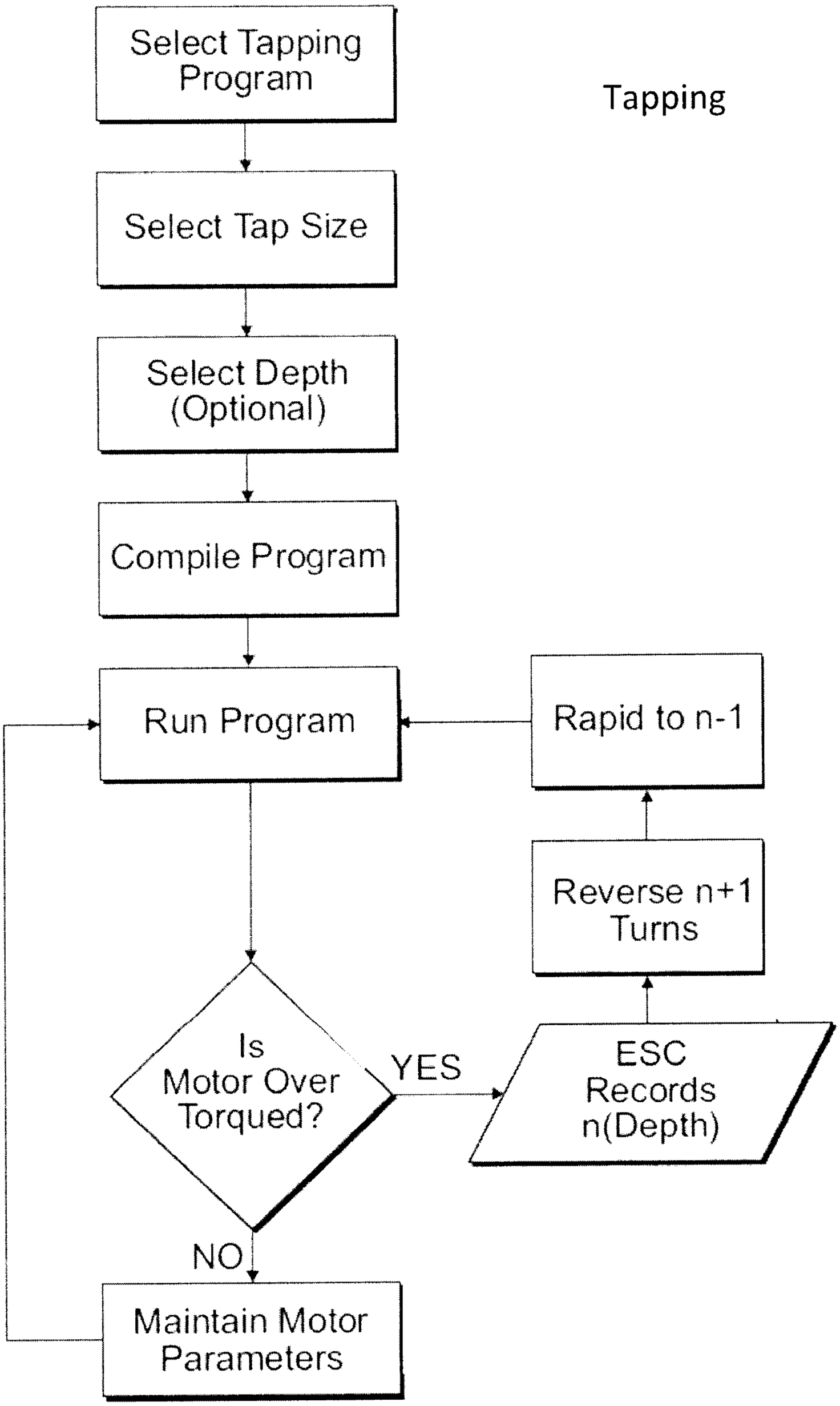

Tapping
Select Tapping Program
Select Tap Size
Select Depth (Optional)
Compile Program
Run Program
Rapid to n-1
Reverse n+1 Turns
Is Motor Over Torqued?
YES
ESC Records n(Depth)
NO
Maintain Motor Parameters

FIG. 5

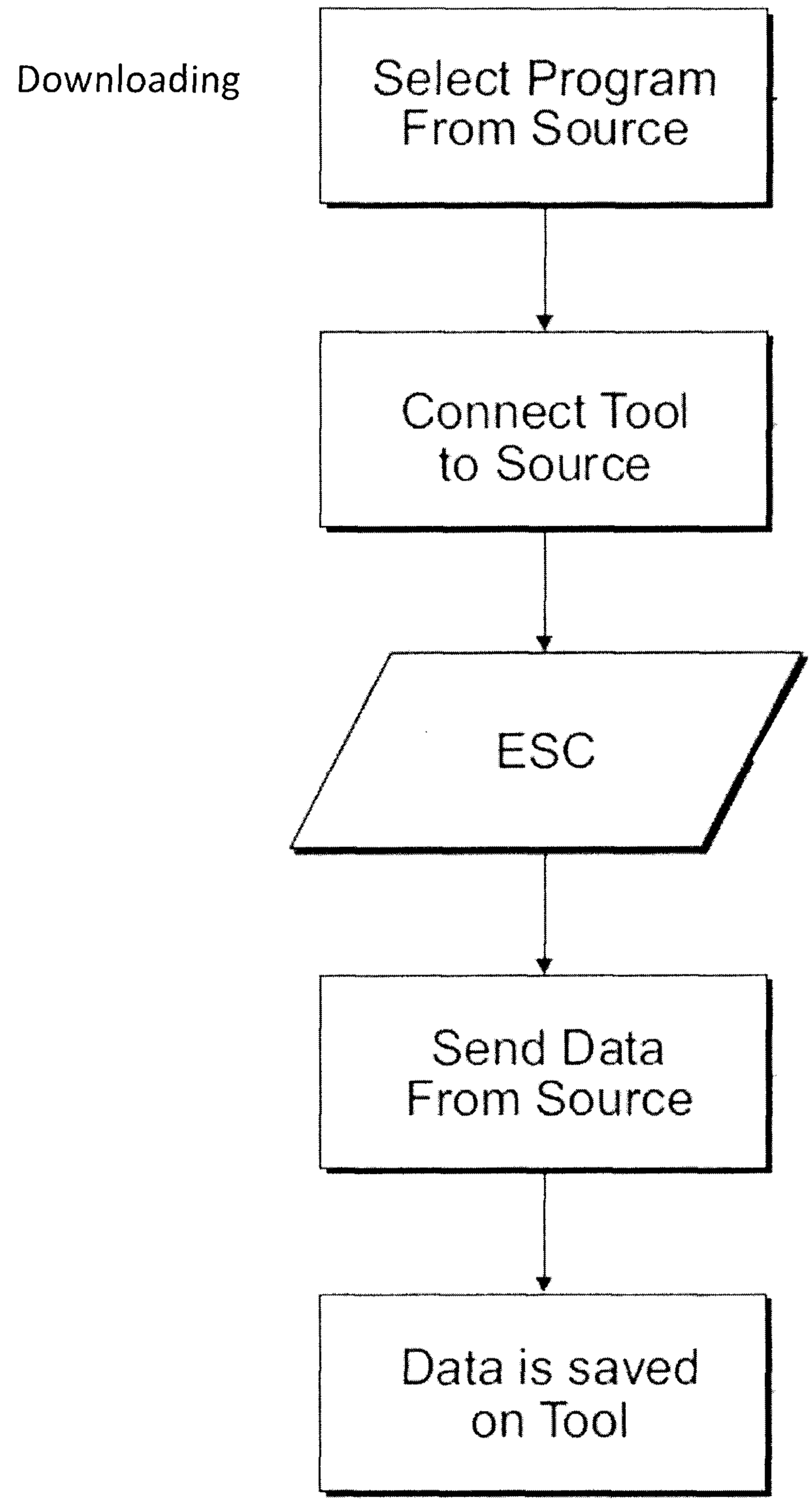
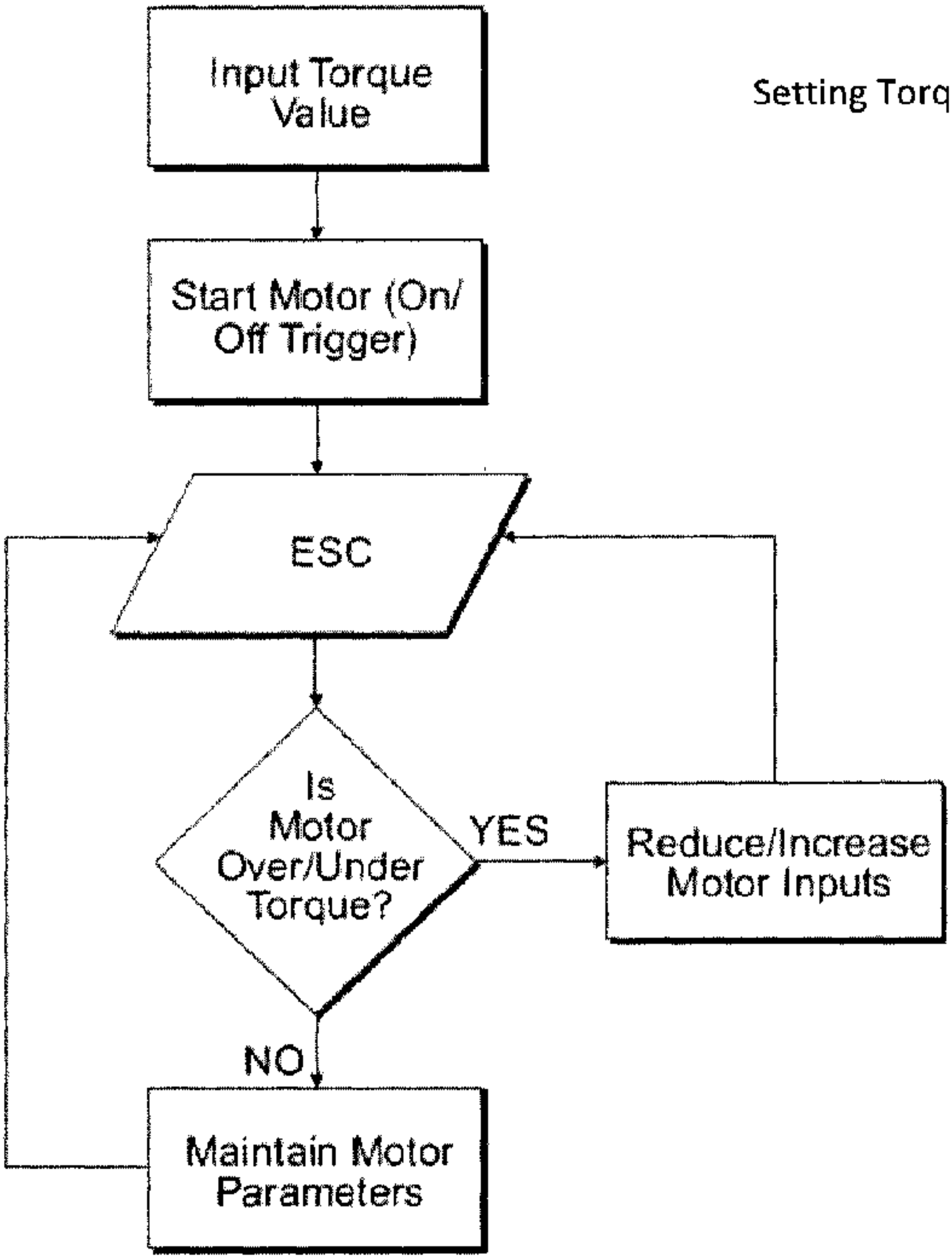

Downloading
Select Program From Source
Connect Tool to Source
ESC
Send Data From Source
Data is saved on Tool

FIG. 6

Setting Torque