AN1130
APPLICATION NOTE

AN INTRODUCTION TO SENSORLESS BRUSHLESS DC MOTOR DRIVE APPLICATIONS WITH THE ST72141

by Microcontroller Division Applications

Electric motors are an essential component of our industrialised society with no less than 5 billion motors built world wide every year.

Brushless DC motors are already used in hard disk drives and many industrial applications, and their market share is growing significantly in automotive, appliance and industrial applications.

The ST72141 has been developed by STMicroelectronics to control synchronous motors or, more specifically, 3-phase brushless DC motors. The most common applications of this type of motor are industrial control, automotive equipment, refrigerators, air conditioners, compressors and fans, where brushless DC motors are already used due to their high efficiency, silent operation, compact form, reliability and longevity.

The ST72141 devices are members of the ST7 microcontroller family designed specifically for motor control applications and including A/D converter and SPI interface capabilities. They include an on-chip peripheral for control of electric brushless DC motor either in sensor or sensorless mode.

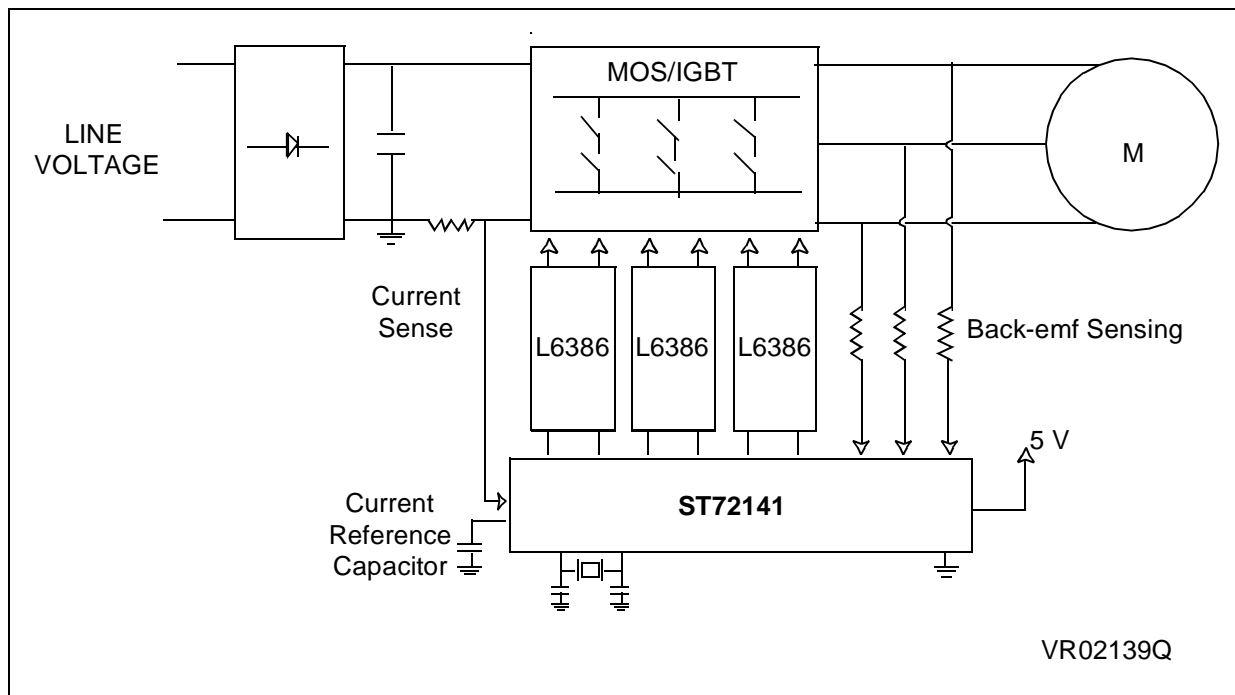**Figure 1. ST72141 Typical Application Block Diagram**

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The ST7 on-chip Motor Controller can be seen as a Pulse Width Modulator multiplexed on six output channels and a back Electromotive Force (Back-EMF) zero-crossing detector for sensorless control of Brushless DC motors.

The Motor Control peripheral of the ST72141 has 4 main parts:

– End of Demagnetisation and Back-EMF zero crossing detector

– Delay manager

– PWM manager (the peripheral needs a PWM signal to run the motor)

– Channel manager

The purpose of this application note is to explain the main functionality of the different parts of the motor control peripheral and the basic principles of sensorless operation. There are three main sections:

– Basic Theory of Brushless DC motors

– ST72141 Motor Control Principles

– A description of the ST72141 motor control peripheral and functionality

1 BRUSHLESS DC MOTOR BASICS

1.1 MAIN CHARACTERISTICS

Brushless DC motors consist of two coaxial magnetic armatures separated by an air gap. In certain types of motor,

– The external armature, the **stator**, is fixed.

– The internal armature, the **rotor,** is mobile (the rotor can also be external in certain cases).

The stator is the induced part of the machine.

The rotor is the inductor of the machine.

In brushless DC motors, the internal armature, the rotor, is a permanent magnet. This armature is supplied by a constant current (DC).

The external armature (stator) is polyphased (3 phases in our case) and is covered by polyphased currents. The pulsation of these currents is ω**.**

We say that the machine is a synchronous machine because, if Ω is the angular speed of the rotor, we have the relation:

$$\Omega=\omega/p$$

In a Brushless DC motor, the rotor is a permanent magnet, this type of motor has almost the same properties and physical laws as a DC current machine.

An electric motor transforms electrical energy into mechanical energy. Two main characteristics of a brushless DC motor are:

– It has an electromotive force proportional to its speed

– The stator flux is synchronised with the permanent magnet rotor flux.

The back electromotive force (as we will see in this document) is the basis of one the ways of driving brushless DC motors with the ST72141 microcontroller in sensorless mode.

1.2 PHYSICAL LAWS AND MAIN MATHEMATICAL EQUATIONS

1.2.1 Induced back electromotive force (back-EMF)

Figure 2. Brushless Permanent Magnet DC Motor Basics
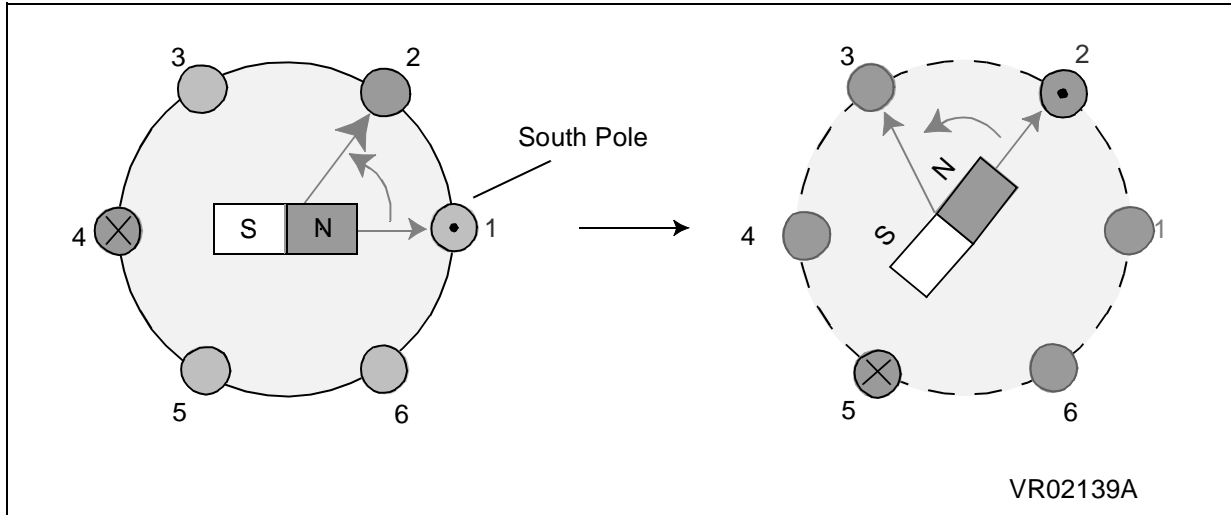
Brushless Permanent Magnet DC Motors are synchronous motors, their stator flux and rotor mechanical rotation speeds are the same.

– Stator description: 3-phase windings.

– Rotor description: Permanent magnet.

The electromechanical characteristics of the motor depend directly on the induction value or more exactly on the flux going through the air gap.

The rotor is the inductor of the machine and its rotation creates a flux in the air gap. From this flux comes the back-EMF.

The back-EMF is the voltage induced in a winding by the movement of the magnet in front of this winding. It is independent of the energy supply to the motor.

The back-EMF is directly proportional to the rotation speed, the rotor flux and the number of turns in the corresponding winding where we want to calculate the back-EMF.

In one turn of the winding, the back-EMF equation is:

$$e = -d\Phi/dt$$

where Φ is the rotor flux

In a complete winding, the back-EMF equation is:

$$E = nN\Phi$$

where E is in V, N is the speed (rotation per second), Φ is in Wb

For a given rotor flux, E and N have the same sign so the rotation sense of the rotor defines the sign of the back-EMF.

E will be at its maximum when the variation of the flux is maximum so when the rotor passes from a North pole to a South pole for example. This means that the back-EMF is at maximum when the rotor flux is perpendicular to the phase.

Note that Pe=E*I where Pe is the useful electric power (mechanical power), E is back-EMF and I is the current in the motor.

1.2.2 Torque

The torque equation for the motor is:

$$C=k\Phi I$$

where I is the current in the motor, Φ is the rotor flux and k is a constant giving the direct proportionality of the torque to the current and the flux.

The power of the motor is then:

$$Pm=C*\Omega$$

where Ω is the angular speed of the rotor.

The ST72141 offers 2 ways of controlling the motor, Voltage mode and Current mode:

– Current mode allows you to control the torque directly as it is directly proportional.

– Voltage mode allows you to control the speed and to set a maximum torque limit (set by the current limitation).

2 ST72141 CONTROL METHOD BASICS

2.1 PRINCIPLES OF 6-STEP MOTOR CONTROL

2.1.1 Application Example

Figure 3. 6-step drive, 120°
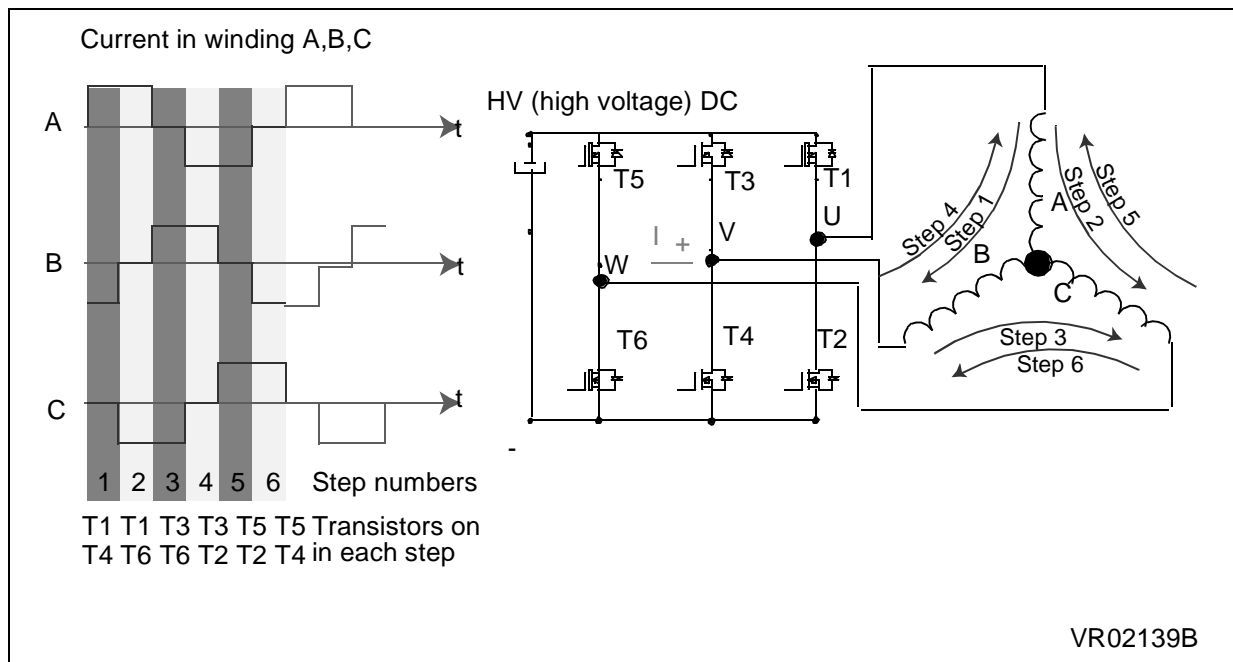
In the ST72141, the motor control is based on a six-step principle with a standard triple half bridge.

– T1,T3,T5 are the high side transistors of the A, B and C phases

– T2,T4,T6 are the low side transistors of the A, B and C phases of the motor

Figure 3 shows the ideal current in each of the motor windings.

During one electrical cycle (6 steps), there are two steps during which there is no current in the winding.

During each step, there are always two of the three windings that are biaised. One in one direction and the other in the opposite direction.

For example in step 1: Phase A is positive-biaised so the current in this winding is positive.

Phase B is negative-biaised, so the current in this winding is negative.

There is no current in phase C. When controlling the motor with the ST72141 in sensorless mode, we will read information on the phase which is not energised, (phase C in step 1 of the example). This information will allow us to determine the real position of the rotor so we can modify the PWM outputs accordingly and drive the motor with maximum efficiency.

2.1.2 Control theory

Controlling the motor requires knowing the position of the rotor at each step:

There are two possible way of obtaining this information:

– Hall effect sensors (sensor mode)

– Back-EMF detection (sensorless mode)

The ST72141 can manage either of the above two possibilities but in this application note, we will mainly deal with sensorless mode.

Back-EMF detection consists of reading, at each step in the non-energised phase, the instant when the back-EMF crosses zero. To get maximum efficiency from the motor, the commutation should take place when the current in a winding is in phase with the back-EMF in the same winding.

The control principle is about keeping the following two signals in phase:

– Current generated by inverter in the motor windings

– Back-EMF voltage induced by the rotor flux in the motor winding

Figure 4. Back-EMF and current in phase in a winding.
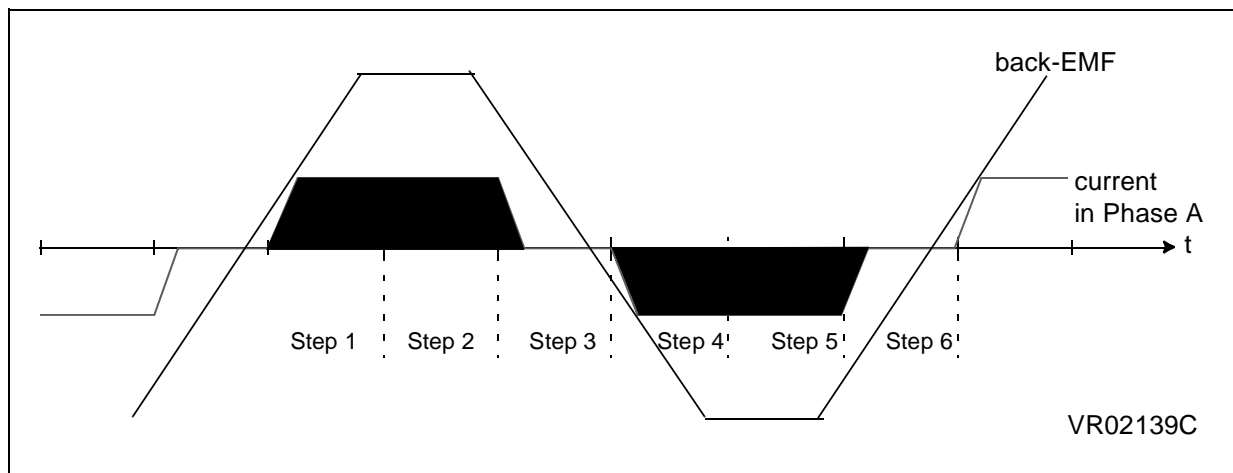
Best efficiency:

The best efficiency is obtained when the 2 signals shown in Figure 4 are in phase. Effectively, as the useful electrical power (mechanical power) of the motor is given by the equation Pe=E*I, the product will be maximum when the Back-EMF and the current are in phase.

2.2 DRIVING MODES AND REGULATION LOOPS

2.2.1 Driving modes

The ST72141 has 2 different motor driving modes: voltage mode and current mode.

Current mode allows you to permanently control the torque by changing the motor reference current, because torque is proportional to current. The current in the windings is regulated in real time and there is a true DC current flowing through the DC Bus. Current mode also allows the current for each of the 6 steps to be finely controlled as the current control is done the PWM cycle.

Voltage mode allows you control the speed easily by changing the motor reference voltage. It does not give you fine control of the current but you can limit the current and consequently the torque to a maximum value. The voltage control is done by the PWM cycle.

2.2.2 Regulation loops

A closed loop is used for speed regulation. It is the second regulation loop of the ST72141.
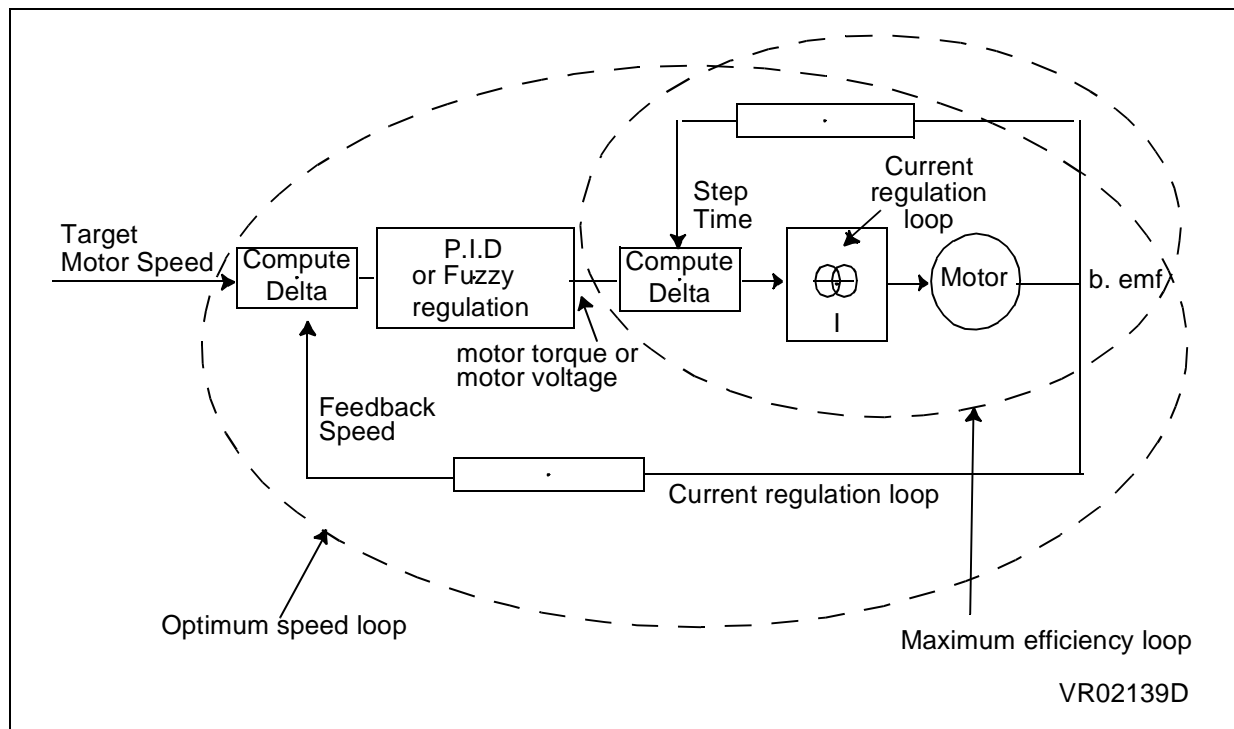
Figure 5. Regulation loops

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Figure 5 shows the 2 regulation loops of the ST72141. The first regulation loop is the auto-commutation efficiency loop. This loop keeps the Back-EMF and the winding current signals in phase. This loop returns the step time that is the actual speed. The second loop is the speed regulation loop which maintains the motor at its target speed.
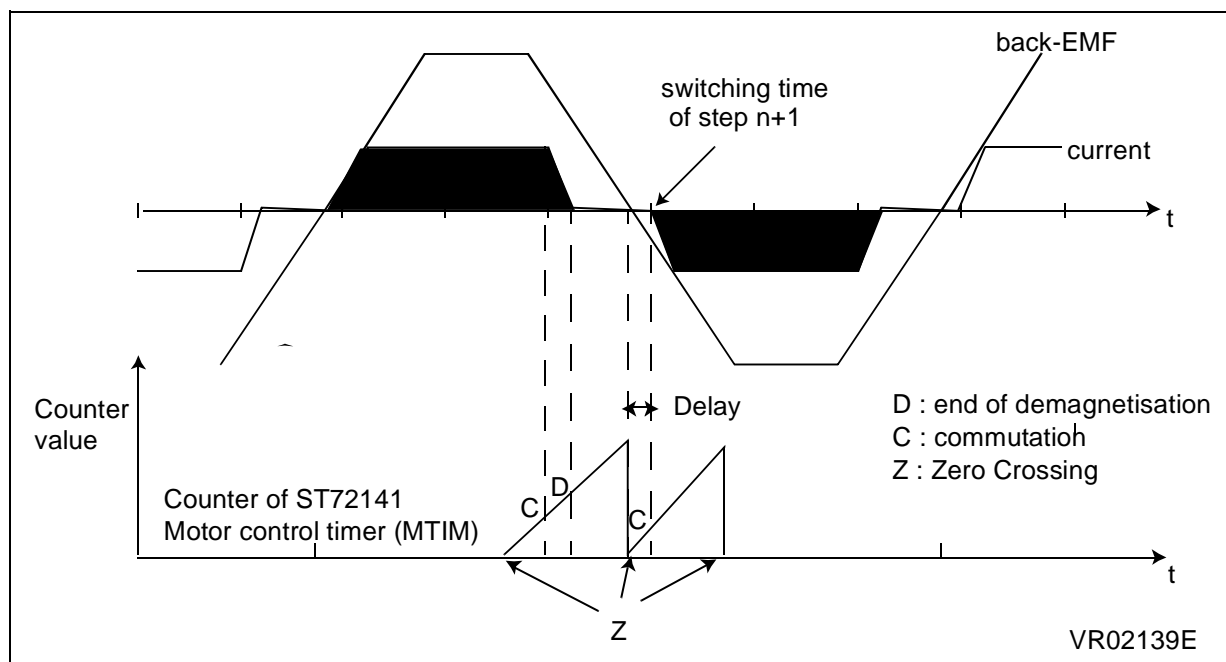
3 ST72141 MOTOR CONTROL PERIPHERAL

3.1 MANAGEMENT OF COMMUTATION, DEMAGNETISATION, ZERO CROSSING EVENTS.

The control process of the motor with the ST72141 is based on 3 events:

– Back-EMF zero crossing event (Z event)

– Commutation (C event)

– End of demagnetisation of a winding (D event)

Figure 6. Event timing diagram

End of demagnetisation and Zero crossing of the back-EMF are physical events, the commutation event is computed by the motor control coprocessor of the ST72141.

The computed delay is the time between a zero crossing event and the next commutation. This delay is either computed from the value of the internal 8-bit timer at the actual zero crossing event (n) or from the value at the zero crossing event before (n-1). This is in order to minimise the effect of motor dissymmetry. The choice between n and n-1 is done by software.

If the speed increases for example, then the zero crossing event will happen earlier and the computed delay has to be decreased to keep the 2 signals in phase.
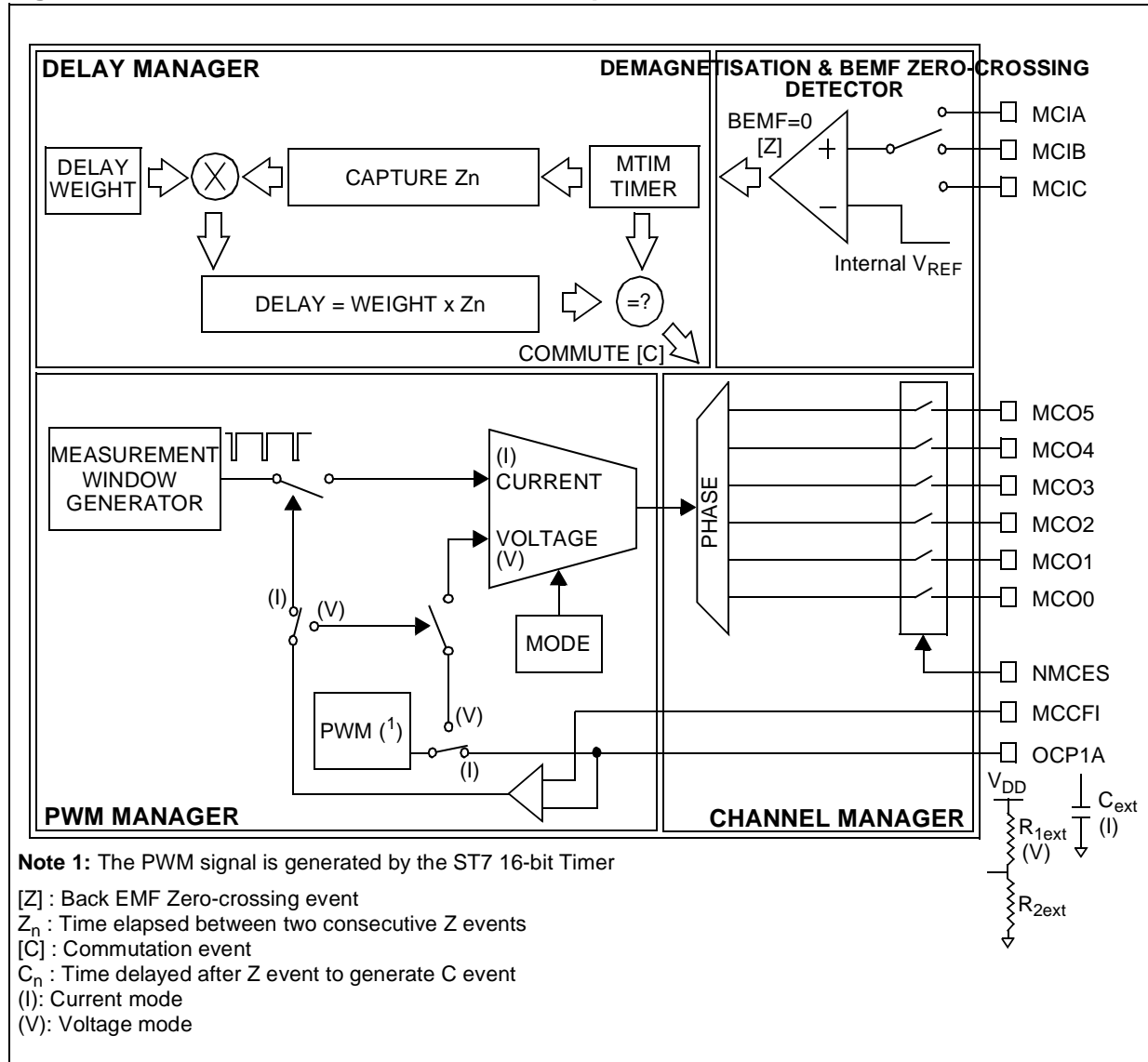
The Motor control peripheral manages the three events always in the same order:

The Z event generates C after a computed delay then waits for the D event. The time between two consecutive Z events corresponds to the step time in auto-commutated mode of the motor.

3.2 STRUCTURE AND FUNCTIONALITY OF THE MOTOR CONTROL PERIPHERAL

The motor control peripheral is divided into four different parts.

Figure 7. Overview of the Motor Control Peripheral

Note 1: The PWM signal is generated by the ST7 16-bit Timer

[Z] : Back EMF Zero-crossing event
Z_n : Time elapsed between two consecutive Z events
[C] : Commutation event
C_n : Time delayed after Z event to generate C event
(I): Current mode
(V): Voltage mode

3.2.1 Zero-crossing and demagnetisation detector

The detection of the Z event (zero crossing) and the D event (end of demagnetisation) is managed by the same part of the peripheral. These events will occur on phases A, B or C depending on which step of the 6-step cycle we are in. The feedback signals from these phases are connected to the MCIA, MCIB and MCIC inputs of the microcontroller.

3.2.1.1 Zero crossing event (Z event)
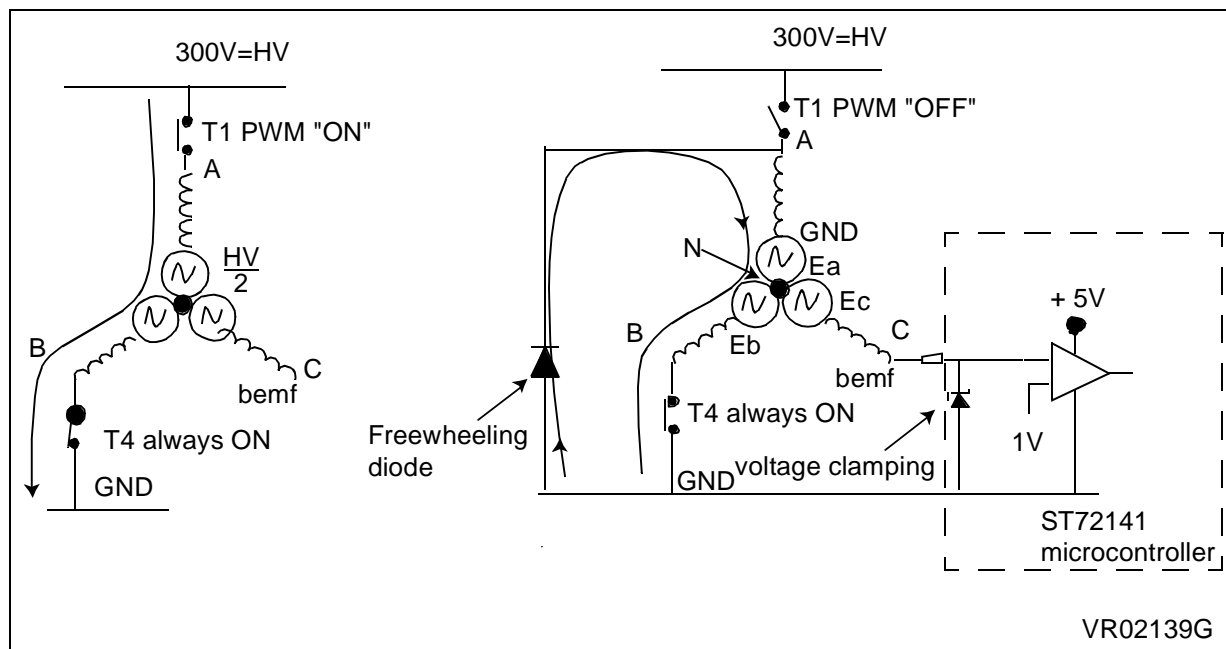**Figure 8. Zero crossing event detection principle**

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Figure 8 shows two states of the motor control, what happened before the state shown on the left is that, winding C has been demagnetised. A filter time of 20µs has passed, the window for reading the back-EMF is now open. Each time T1 transistor is off, current flows in the free-wheeling diode and the voltage at point A is at ground.

If Ea is the back-EMF on phase A, Eb the back-EMF on phase B and Ec the back-EMF on phase C, when Ec crosses zero, we have Ea=-Eb, so N is at ground potential. This means that no virtual ground has to be created.

The back-EMF zero crossing event is sampled at the output of the comparator, at the frequency of the PWM signal applied to T1 in sensorless mode. The voltage from C is clamped at + 5V/-0.6V (but what we are interested in is around 0V) by the on-chip clamping diode.

Note: This will also work with a delta-connected motor.

One of the inputs of the comparator is the voltage signal from the C winding. The other input of the comparator is a threshold voltage (there are 4 different threshold voltages that can be chosen between 0.2, 0.6, 1.2 and 2.5V by software). The ST72141 waits for the back-EMF signal in the C winding to reach the threshold voltage. The hardware needs a PWM signal on T1. During each off-time, the voltage signal from the C winding is put to ground. Consequently the ST72141 only reads the Back-EMF signal and can detect when it reaches the threshold voltage.

The PWM is generated by the PWM manager part of the peripheral. The voltage signal from the C winding will be sampled at T1 PWM frequency at the comparator output.

Figure 9. Oscilloscope waveforms
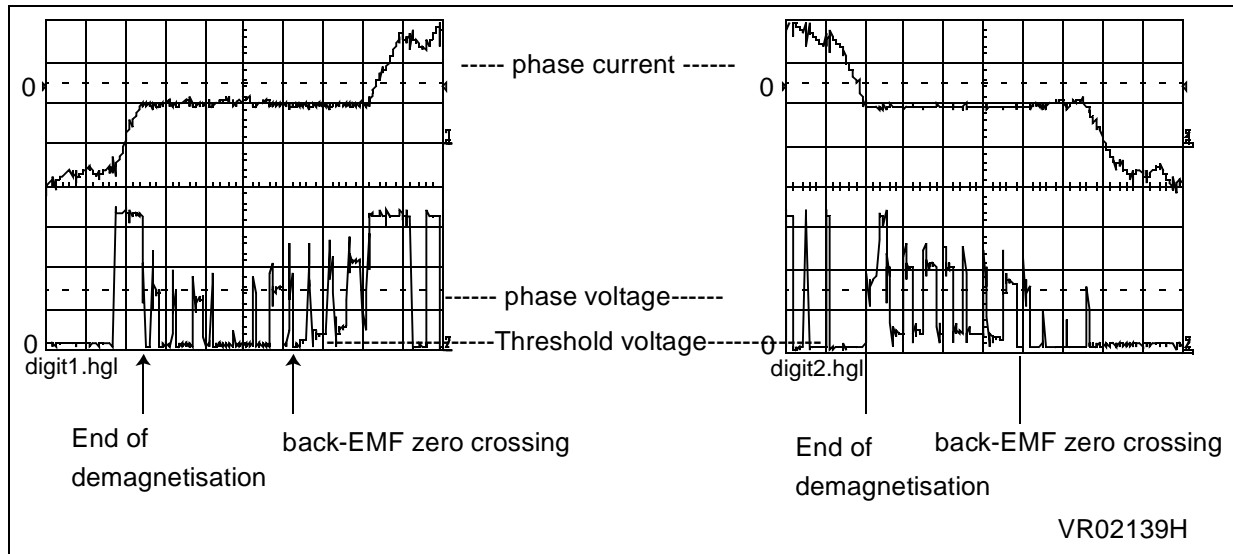
In the first graph in Figure 9 we can see that the current in the winding (phase current) goes from negative to zero. During the step where the phase is not energized, the back-EMF signal goes from negative to positive. We can see that during the off time of the PWM applied to the high side transistor, the back-EMF signal is taken down to ground. The ST72141 then waits for a rising edge crossing the threshold voltage. So, as long as the back-EMF is negative, the signal is taken down to 0V at each off-time, once the signal becomes positive, the value of the back-EMF is added to the 0V and we can see that the signal reaches the threshold voltage during the off-time of the high side transistor. When this occurs, the comparator output state changes and the ST72141 detects the zero crossing event.

In the second graph, we see the opposite transition, the current in the winding goes from positive to zero. During the step where the phase is not energized, the back-EMF signal goes from positive to negative. The ST72141 then waits for a falling edge crossing the threshold voltage. So, as long as the back-EMF signal is positive, the value during the off time is greater than 0V and decreasing. Once the signal crosses the threshold voltage (it is seen during the off time), the comparator output state changes and the ST72141 detects the zero crossing event.

In each case, the signal is sampled at the PWM frequency at the output of the comparator and the PWM is applied to the high side transistor. For the zero crossing event detection, the PWM signal is always applied on the high side transistor of the corresponding phase.

3.2.1.2 End of Demagnetisation event (D event)

The method of detecting the end of demagnetisation event is exactly the same as for the zero crossing event and it is managed by the same part of the peripheral. The motor control peripheral always manages the three events in the same order. A Z event generates a C event after a delay and then waits for a D event.

Figure 10. End of demagnetisation
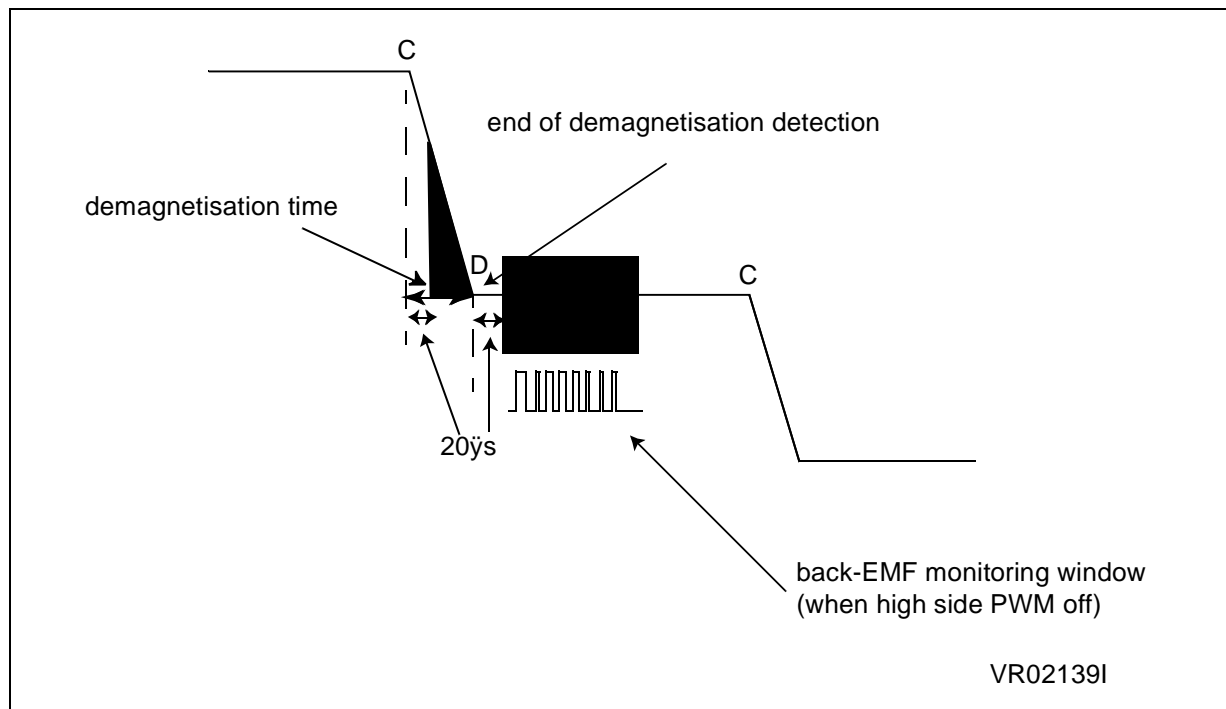
After the commutation we start accelerating the winding demagnetisation (see application note titled "Implementing a sensorless PMDC Motor Drive using the ST72141" AN1129). There is a filter time of 20μs after the commutation to avoid detecting the End of Demagnetisation event too early. The End of demagnetisation detection is done by the same comparator but this time with output sampling at 800KHz.

In sensorless mode, the output sampling frequency of the comparator is the PWM frequency for the zero crossing event and 800KHz for the End of demagnetisation event.

In sensor mode, the sampling frequency is 800KHz for the zero crossing event. The end of demagnetisation event is not important in sensor mode.

So, during demagnetisation acceleration, the PWM signal output by the PWM manager is applied on the high side transistor or on the low side transistor of the winding we are driving (depending on the step status). To accelerate the demagnetisation, we apply the maximum reverse voltage on the winding. For example, if one of the ends of the winding was at 0V the step before, we will apply HV (high voltage) during demagnetisation (during the PWM off-time of the transistor) and so on for the opposite configuration. If the end of the winding was at the HV

the step before, we will take it down 0V during demagnetisation (see application note AN1129).

This is shown in Figure 9.

In the first graph, the current in the winding was previously negative, so the extremity of the winding was brought to ground and we can see on the phase voltage signal in the lower part of the graph, that just after the commutation, the voltage at the extremity of the winding is high voltage (motor voltage). Once demagnetisation is finished, the winding extremity is a floating point and the voltage falls to a value near to ground. The ST72141 waits for the falling edge of the End of Demagnetisation event. When the voltage signal reaches the threshold voltage, the state changes at the output of the comparator and the ST72141 detects the End of Demagnetisation event. In falling edge configuration, to can be difficult to detect End of Demagnetisation events, in this case we use the software demagnetisation feature of the ST72141 (see Application Note AN1082).

A software End of demagnetisation event is generally required when the ST72141 is waiting for a falling edge on the signal used for End of demagnetisation detection. In this case the back-EMF signal goes from negative to positive and the PWM signal is applied on the high side transistor. At the end of demagnetisation, the phase extremity which is read to detect the D and Z events becomes a floating point and the potential of this phase will drop and reach the threshold voltage (average 0.6V). However, if the motor speed is suddenly increased by the user, by changing the current in the motor or the target speed, the Zero crossing event will happen earlier. In this case the back-EMF signal might already be positive when the phase extremity becomes a floating point. The signal will not cross the threshold voltage and the ST72141 will not detect the End of demagnetisation event. As a consequence, the ST72141 won't open the Z event detection window 20µs afterwards and this will disturb the running of the motor, which will stop if an event is not detected. So, to avoid this problem, we force an End of demagnetisation event and so the Z window detection is opened in all cases.

There are four different threshold voltages for detecting the End of Demagnetisation event. They are the same as the thresholds for detecting the Zero crossing event: 0.2, 0.6, 1.2, 2.5V

In the second graph, the current in the winding is going from positive to zero. High voltage (motor voltage) has previously been applied to the extremity of the winding and we can see on the graph that during demagnetisation, the extremity of the winding is brought to ground. At the end of demagnetisation, the voltage rises and reaches the threshold voltage. At that time the ST7141 detects the rising edge of the End of Demagnetisation event.

3.2.1.3 Summary

The detection of the Zero crossing event (Z event) and the End of Demagnetisation event (D event) is managed by the same part of the peripheral.

After the C event (commutation), demagnetisation of a winding is accelerated. There is a filter time of 20µs after the commutation to avoid detecting End of demagnetisation too early. After the D event, there is another 20µs filter time and the Z event detection window is opened.

In sensorless mode, the sampling frequency of the phase voltage signal is 800KHz for the detection of the D event and the PWM frequency for the Z event.

The edges of the D and the Z event are opposing. In Figure 9 we can see in the first graph that when there is a falling edge for the D event, there is a rising edge for the Z event and the opposite configuration in the second graph.

The threshold voltages for the detection of these 2 events are the same and can be chosen from 4 different values: 0.2V, 0.6V,1.2V and 2.5V (software selectable).

The PWM signal is applied always on the high side transistor for the detection of the zero crossing event and can be applied either on the high side or on the low side transistor during demagnetisation in order to accelerate it. It depends on the configuration.

3.2.2 Delay manager

The delay manager is one of the key functions of the microcontroller. In order to keep the motor at optimum efficiency (keeping the back-EMF signal and the current in the motor in phase), the microcontroller automatically computes the delay between the zero crossing event and the next commutation. This computation is based on from a multiplication of the step time and a particular coefficient, the delay coefficient.

Figure 11. Delay manager
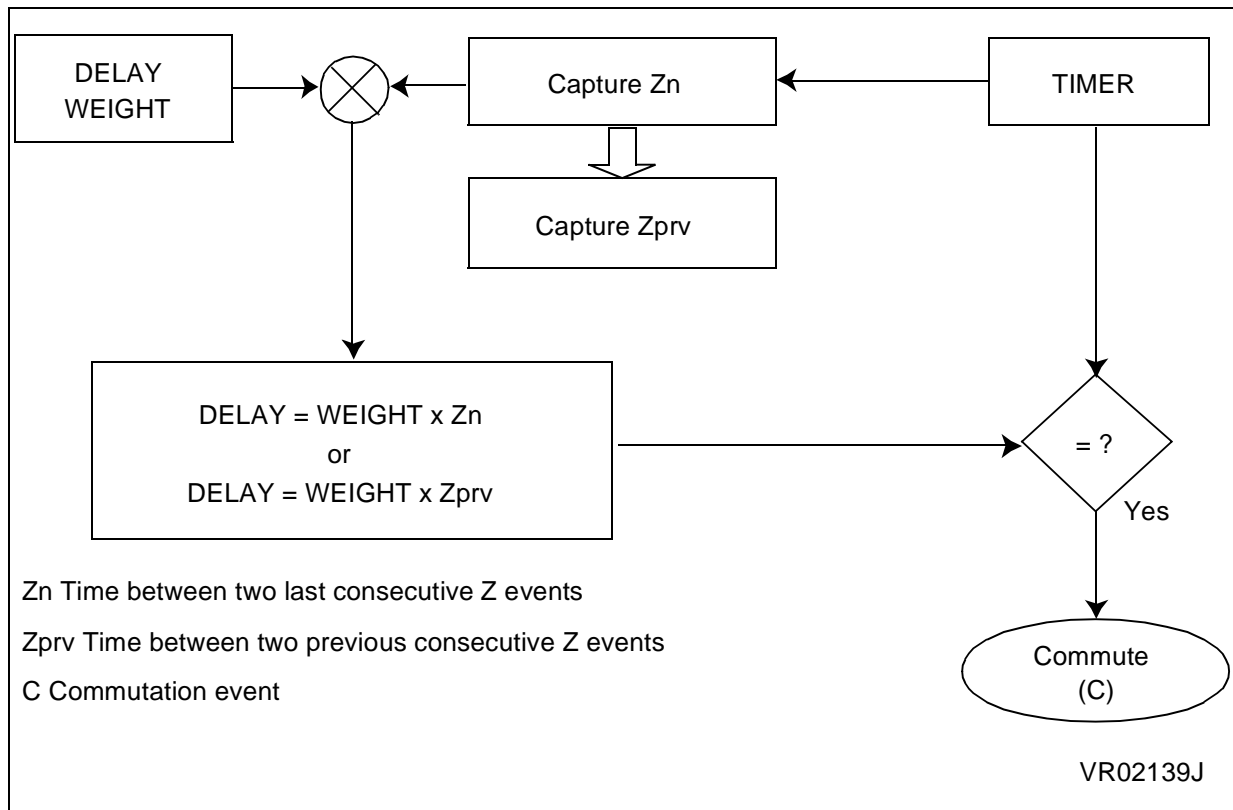
On each zero crossing event, the internal 8-bit timer of the ST72141 is reset in auto-commutated mode. Just before being reset, the value of the timer is captured, this gives us the interval between two zero crossing events (which is the step time in auto-commutated mode). The value of the step time (the timer value) is multiplied by an 8-bit coefficient, the delay coefficient (WEIGHT) and then divided by 32 (fixed) which provides enough resolution with respect to the total time between two zero crossing events. The result then gives the time to wait before the next commutation. So, when the timer value (which has been reset by the Zero crossing event) reaches the result of this computation, the commutation event occurs.

The coefficient is set by the software programmer, it is a function of the motor characteristics, application environment and also speed.

There is an automatic compensation in the case of dissymmetrical motors. Effectively, the software programmer can choose to compute the delay between last two consecutive Z events or between the previous two consecutive Z events. Z previous is intended for compensation in case of dissymmetrical motors.

The delay coefficient is not auto-refreshed by the microcontroller, some tests have to be done to determine the best value of the coefficient depending on motor speed. For example, the higher the speed, the lower the value of the delay coefficient. If speed increases, the zero

crossing event will happen earlier, so the delay between the detection of the Z event and the next commutation has to be decreased (so the delay coefficient has to be decreased).
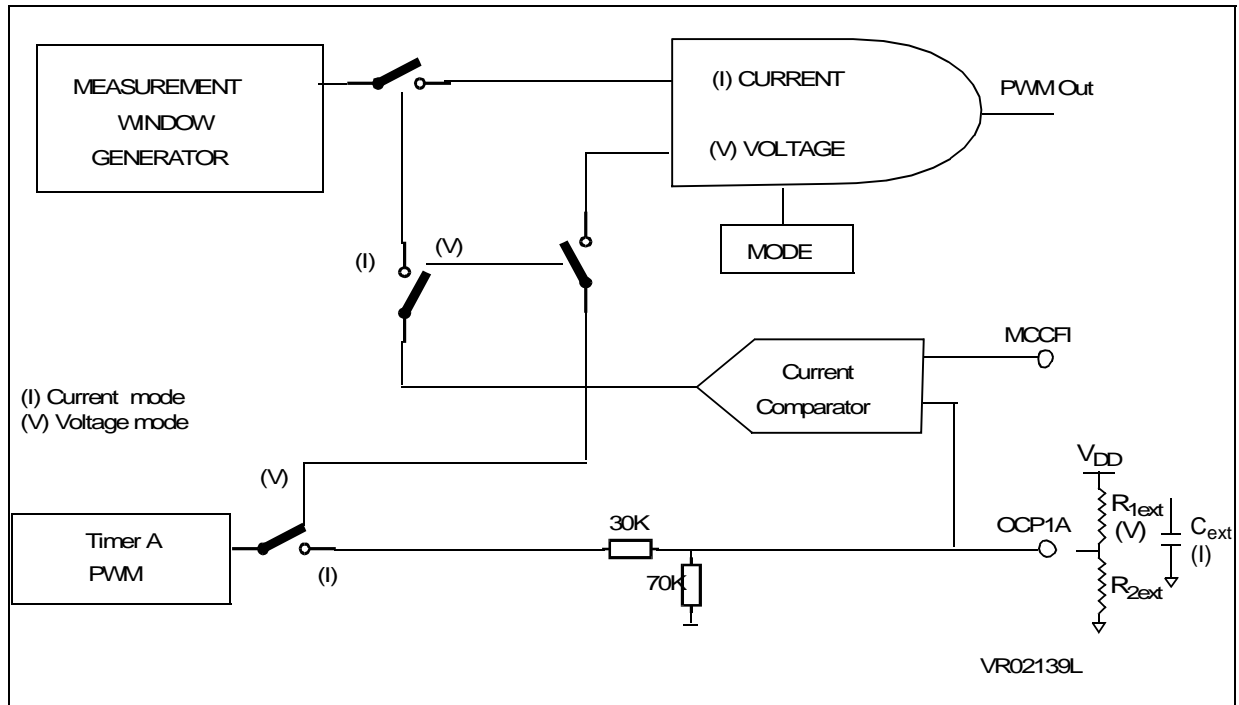
Figure 12. Step time division
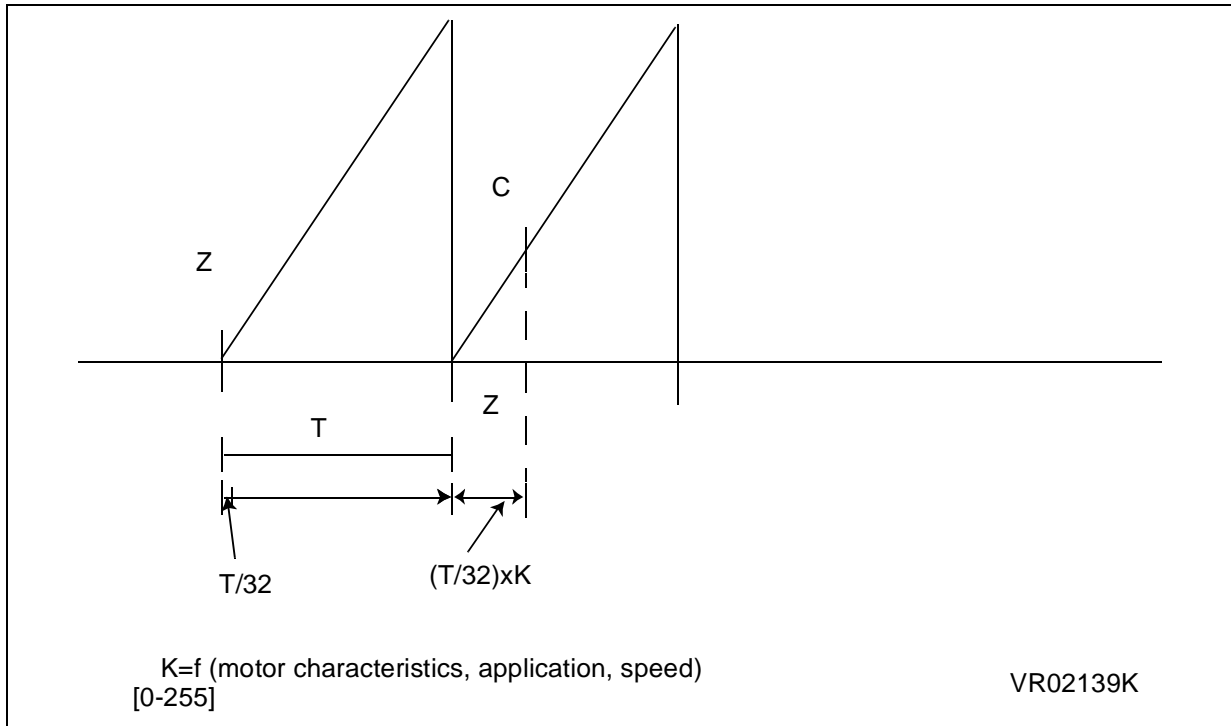
The value of Zn captured from the timer, is multiplied by the delay coefficient and then divided by 32 to give the real delay between the zero crossing event and the next commutation.

3.2.3 PWM manager

Figure 13. The PWM manager

The PWM manager manages two different things that integral parts of the way the ST72141 drives the motor:

– Current regulation or limitation

– Generation of the PWM signal applied on the switches.

The PWM manager has two distinct motor driving modes: voltage mode and current mode. In both cases, Timer A (which is not in the motor control peripheral but is an on-chip peripheral of the ST72141) has an essential role.

In Figure 13, the PWM manager uses the paths indicated by the (I) symbol for current mode and by the (V) symbol for voltage mode.

3.2.3.1 PWM manager in voltage mode
Figure 14. Current limitation in voltage mode control
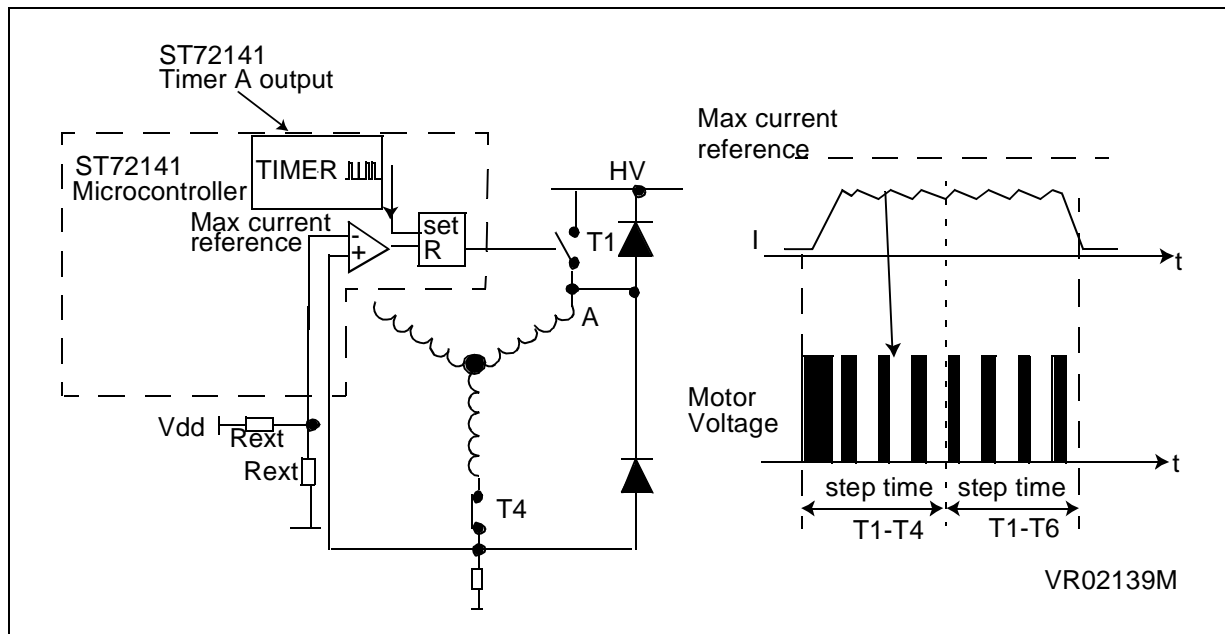
In voltage mode, the PWM of Timer A gives the voltage which is supplied to the motor, it is the voltage control of the motor. The PWM of Timer A is also applied directly to the switches in order to be able to detect the Z and D events in the PWM off-time. The sampling frequency of the phase voltage signal for detecting the Z event is the Timer A frequency.

In voltage mode control, we can set a limitation to the current. The current limitation can be set by the user with an external resistor divider as shown in Figure 14. When the current feedback reaches the maximum reference current at the comparator input, the transistor to which the PWM is applied is put in off state until the current feedback becomes less than the maximum current limit. So, one of the inputs of the internal comparator is the maximum current limitation (OCP1A pin), the other input is the current feedback from the motor (MCCFI pin).

This current limitation is for protection and should normally never be reached when running the motor correctly.

Note: In speed regulation, the Timer A PWM duty cycle only has to have the right value to start the motor. Once the target speed is reached, the PWM duty cycle will be adjusted automatically by the ST72141.

3.2.3.2 PWM manager in current mode control

Figure 15. Current regulation in current mode control
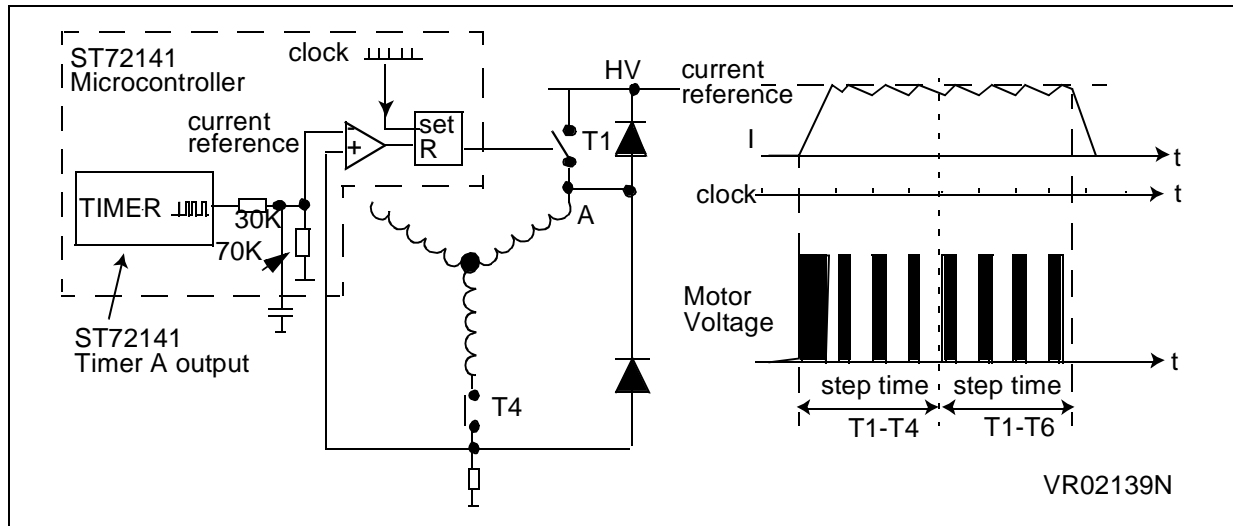
In current mode, the PWM output by Timer A represents the reference current which will be applied to the motor. The PWM duty cycle is the current level at which we want to polarise the motor. Due to the ST72141-internal resistor divider (30Kohms, 70Kohms) at a 100% duty cycle, the reference current is 3.5V. This corresponds to the maximum current to be applied to the motor for maximum torque. The PWM duty cycle is obtained by dividing the reference current we want in the motor (depending on the torque needed) by the maximum current. For example, if the maximum current is 1A and if the reference current has to be 0.2A, the PWM duty cycle will be 20%.

An external capacitor has to be added in order to filter the reference current PWM signal.

So, for the internal comparator, one of the inputs is the current feedback of the motor (MCCFI pin), the other input is the reference current given by the filtered PWM signal from the timer A.

We see in Figure 13 that the internal clock is used in current mode control. The internal clock outputs a PWM signal as well. The frequency of this signal is user-selectable from several values and the off-time of this signal is also user-selectable (from 4 different values: 5, 10, 15, 30 μs) with a minimum value of 5 μs needed to allow the stabilization of the system. The PWM signal frequency output by the clock represents the current frequency used to supply the motor. The off-time of this PWM signal is variable, with a lower limit of 5 μs. The PWM signal output by the internal clock is applied to the designated switch. The signal frequency is the same as the back-EMF signal sampling frequency used to detect the Z event. This mechanism has the following procedure:

When the current feedback from the motor reaches the reference current given by the Timer A PWM signal at the comparator input, the internal clock signal is reset. The switch where the PWM is applied is put in off state until the current feedback is lower than the reference current.

That's why the duty cycle of the internal clock is variable. A minimum off-time has to be defined by the software programmer but the duty cycle is modified depending on the motor behaviour.

Note: In speed regulation, the Timer A PWM duty cycle only has to have the right value to start the motor. Once the target speed is reached, the PWM duty cycle will be adjusted automatically by the ST72141.

3.2.3.3 Summary

In voltage mode, the Timer A PWM signal gives the voltage to be applied to the motor. This Timer A PWM is applied to the switches in order to detect the Z and the D events. So, the sampling frequency of the back-EMF signal is same as the Timer A PWM frequency used to detect the Z event. The internal clock is no longer used to generate the PWM signal applied to the transistors.

A current limitation is implemented in voltage mode. The current limitation can be set by an external resistor divider.

In current mode, the Timer A PWM signal gives the reference current to be applied to the motor. This signal has to be filtered by an external capacitor. The internal clock is used and the PWM signal from the internal clock is applied to the switches. the back-EMF signal sampling frequency for detecting the Z event is the internal clock PWM frequency.

In current mode, the current is regulated by comparing the reference current and the feedback current from the motor.

4 STARTING SEQUENCE EXAMPLE

Before starting the motor, the rotor position is not known, so it has to be pre-positioned by software. During the first steps, the back-EMF signal level is too low to be read. So, before it is possible to read the back-EMF signal and because the current at the start-up sequence has to be greater than the load torque plus the friction torque and the motor inertia load, the current supplied to the motor will be higher than that actually required.

So, in current mode and in voltage mode, the Timer A PWM duty cycle during the start up sequence has to be higher than that required during normal functioning.

Figure 16. Current versus back-EMF phase
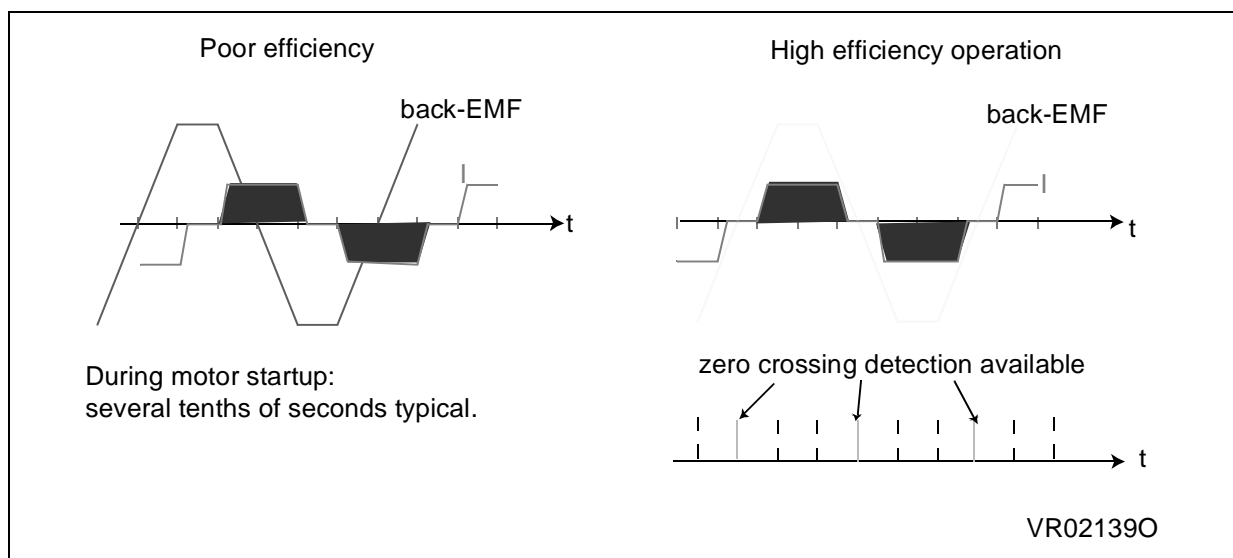
As the back-EMF signal is masked during the first steps, we have start the motor in a specific way in order to detect the zero crossing event after a certain number of steps. This operation is called synchronous (switched) mode or the motor ramp-up.

For a certain number of steps when the motor is started, the consecutive step times and the current are imposed on the motor. These step times progressively decrease in order to accelerate the motor to get a detectable Zero crossing event. After a certain number of Z event detections (this number software selectable) during the motor ramp-up, we start regulating (monitoring back-EMF and Z events) to run the motor with high efficiency. The motor goes into auto-commutated mode. If the motor is not in auto-commutated mode at the end of the ramp-up (with step times imposed to accelerate the motor), then the motor is stopped.

So the motor runs in two modes: First in synchronous (switched) mode then in auto-commutated mode.

Synchronous (switched) mode is handled by to a ramp table which is part of the motor control software. This ramp table contains all the consecutive decreasing step times that have to be imposed on the motor in the start-up sequence. Normally the number of step times that have

to be imposed on the motor is between 30 and 40 but the choice is left to the software pro-grammer and depends on the application. But, whatever the length of the ramp table, if the motor is not in auto-commutated mode in the last step of the ramp-up, it has to be stopped and optionally restarted.

Figure 17. Starting sequence

VR02139P
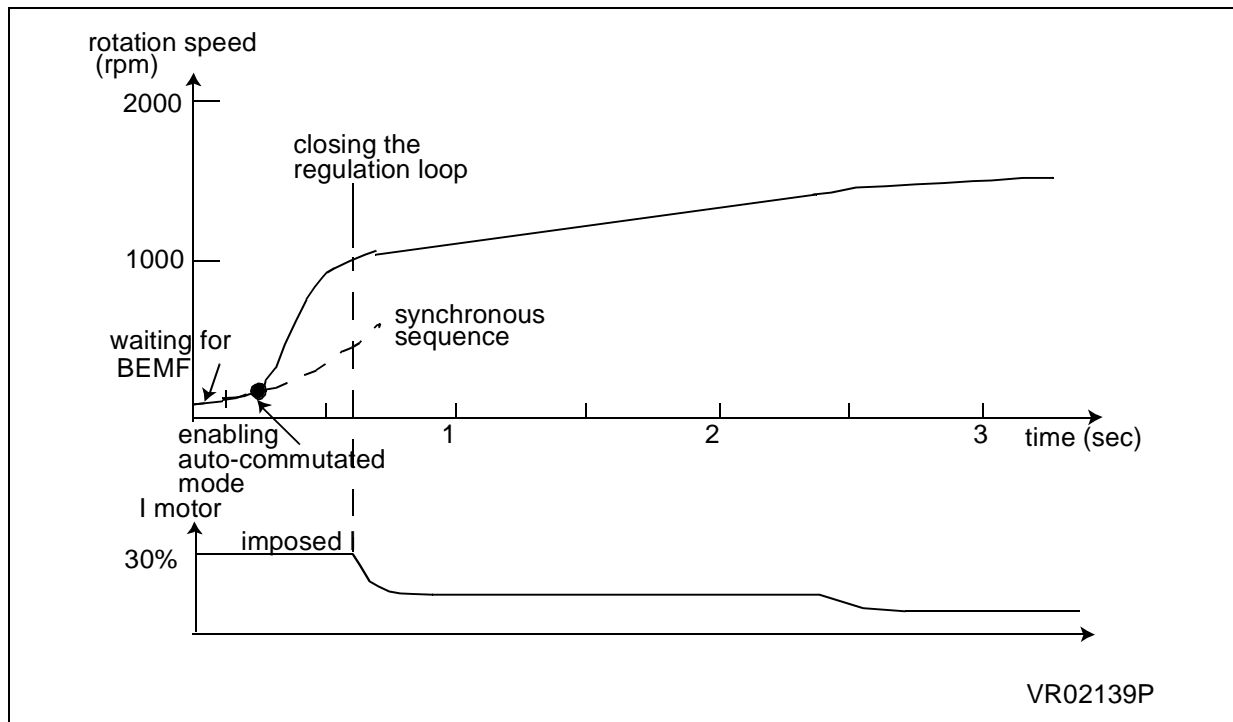
The Figure 17 shows the starting sequence in closed loop mode. The starting sequence is the same in open loop except the fact that the current or the voltage can be changed by the user as soon as the motor is in auto-commutated mode. In closed loop, the current or the voltage is imposed and fixed by the user until the motor enters speed regulation where the level of the current is out of user control (it is auto-regulated by the ST72141).

The motor is allowed to enter the speed regulation loop after a software-selectable number of steps in auto-commutated mode.

5 THE SPEED REGULATION LOOP

In closed loop control mode, in either driving mode (current or voltage), a second main loop, the speed regulation loop, is active. This means that one or several target speeds will be fixed for the motor and regulated by the microcontroller. This is implemented as a speed table included as a text file in the software.

Figure 18. Example of data for 1400 rpm as target speed

Figure 18 shows an example of the data to be provide to the microcontroller for a target speed of 1400 rpm.

In this example, the number of integration steps is 12, meaning that each 12 motor steps, we enter the speed regulation loop in order to correct the error. This number of steps depends mainly on the number of pairs of poles in the motor. Effectively, the number of integration steps is equal to 6*p (6 because an electrical cycle is made up of 6 steps and p for the number of pairs of poles in the motor).

The target speed is 1400 rpm in this example. The target speed and the number of pairs of poles gives the step time. With the step time, the number of integration steps the internal clock frequency, the ratio and the value loaded in the internal timer are computed. These are the 2 most important values for the ST72141 because they used and corrected for speed regulation. The other parameters values like the proportional and integral coefficients and the starting current are given to the peripheral at the same time as the target speed in the software but they are obtained by testing and fine tuning and not computed directly from the number of pairs of poles or any other parameter.

When the motor is started in closed loop, we supply it with the starting current (Timer A PWM duty cycle in voltage or current mode). We can change this duty cycle until the motor has crossed the target speed. Once the motor has crossed the target speed, the PWM duty cycle will be auto-regulated by the ST72141 and the duty cycle will be out of user control.

6 THE ST72141 GENERAL FEATURES

The ST72141has the following general features:

– 8K ROM/OTP/EPROM

– 14 multi functional bidirectional I/Os with

   External interrupt

   13 alternate function lines

   3 high sink outputs (20mA in open drain)

– Two 16-bit Timers with:

   2 input captures

   2 output compares

   External clock input

   PWM and pulse generator mode

One of these timers is used by the motor control peripheral of the ST72141.

– SPI synchronous serial interface

– 8-bit ADC with 8 channels

– SDIP32 or SO34 package

– Enhanced reset (on-chip) system

– Low voltage supervisor

– 3 power saving modes

– Configurable watchdog reset

7 HOW TO RUN YOUR MOTOR THE FIRST TIME

7.1 SOFTWARE

When you run the motor for the first time, it is better to begin in the current mode, open loop configuration. This is because in current mode open loop, you can regulate the current in the motor, you can then find the right parameters for the start-up phase of the motor (the ramp table and the starting current with the right delay). Once you arrive in open loop at the speed you want your motor to run, you can fine tune all the parameters for the running speed. After this, you can switch to in closed loop configuration or voltage configuration. Do not set too high a duty cycle at first for the reference current in current mode open loop but change it progressively starting from a low value and increasing it.

The most important parameters in your application are: The ramp table for your motor, the driving mode and the starting parameters for the motor. All of these are very important and you get them by testing out different values on your motor and fine tuning them.

80% of motor control software is common to all applications. The rest consists of the parameters for the motor, the driving mode, the speed table and the ramp table which are specific to each application.

To fine-tune the parameters for your motor, you can use the Kanda motor control starter kit which is a tool specifically designed in order to fine-tune your application or you can implement a keyboard on your hardware prototype to allow you to change your parameters directly.

7.2 HARDWARE

One thing which is very important to check is the correlation between the software and the hardware part of your application. Different tables in your software indicate to the microcontroller what phase has to be read in order to detect the D and the Z events in the signal depending on the step status. The commutation table indicates the commutation sequence of the six steps. The correspondence between the hardware and the software tables has to be checked very carefully, the step sequence, the phase which has to be read depending on the step status and the edge of the event we wait for on the back-EMF signal coming from the read phase of the motor.

If your motor doesn't run the first time, check the following in order of priority: hardware and software correspondence, the ramp table and the starting parameters.

8 SUMMARY

As we have seen in this application note, the ST72141 (ST7 Motor Control) is particularly suited to driving Brushless DC motors and supports operating modes like:

– Commutation step control with motor voltage regulation and current limitation in Voltage mode

– Commutation step control with motor current regulation, i.e. direct torque control in current mode

– Sensor or Sensorless motor phase commutation in both delta and star connections

– Back-EMF zero-crossing detection with high sensitivity. The integrated phase voltage comparator is directly referred to the full back-EMF voltage without any attenuation (clamping function is provided to protect the microcontroller). A back-EMF voltage down to 200mV can be detected (the detection threshold voltage can be selected from 4 different values: 0.2, 0.6, 1.2 and 2.5V), providing high noise immunity and self-commutated operation over a large speed range

– Real time motor winding demagnetisation detection for fine-tuning the phase voltage masking time to be applied before back-EMF monitoring

– Automatic and programmable delay between back-EMF zero crossing detection and motor phase commutation

The ST72141 is a very powerful and complete technical solution for driving brushless DC motors. It is a complete digital solution, eliminating the need for analog filters and potentiometric dividers.

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