DC BRUSHLESS MOTOR CONTROL SYSTEM

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ABSTRACT: *At the moment most of the drives are made with electric motors. From micromotors to high power engines, they have evolved continuously from a constructive point of view. More and more brushless DC motors are being used. In this paper we propose a DC brushless motor control system that will run with motors that require a supply voltage up to 400V. The system will also have implement a protections and a speed regulation algoritm.*

KEY WORDS: *brushless motor, control system, Hall sensors, regulation algorithm, protection*

1. INTRODUCTION

An electric motor is an electromechanical device that converts electrical energy into mechanical energy. While both AC motors and DC motors serve the same power conversion function in mechanical energy, they are powered, built and controlled differently, the most important difference is the power supply: alternative or direct current. In general, high power alternating current motors do not use brushes, they are very durable and have a long life span. The main disadvantage of these motors is the speed control principle, which is achieved by changing the frequency with special equipment called frequency inverters.

The DC motor has magnetic poles and polar coils on the stator that create the magnetic field of excitation, and for medium and small powers instead of the stator windings, permanent magnets are used. On the motor shaft there is a collector which, by means of the brushes, changes the direction of the current through the rotor winding so that the excitation magnetic field always exerts a force on the rotor. The principle of the brushless DC motor is shown in figure 1.

Changing the direction of rotation is done by changing the polarity of the supply voltage. The motor speed is proportional to the voltage applied to the rotor winding and inversely proportional to the magnetic field of excitation, so the speed is adjusted by varying the voltage applied to the rotor up to the nominal voltage, and for higher speeds by weakening the excitation field.

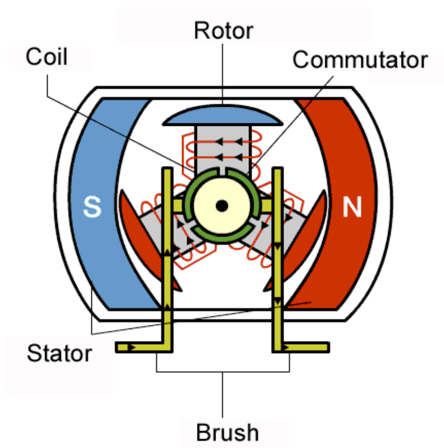

Fig.1. DC Brush Motor

Advantages and disadvantages of the DC brush motor:

- It is easier to control, speed setting is done in voltage.
- Has a great starting torque
- It is more expensive because it requires maintenance (brush change)
- The speed is limited by the friction force (the faster the brush friction is higher).
- Brush engine dissipates energy by rubbing resulting in additional heating.
- Because of the brush sparks, the distortion factor of the feed system increases by the

injection of parasitic impulses. Parasitic voltage pulses disturb other consumers connected to the same network

The alternative to brushless DC motor is brushless motor.

The brushless DC motor, abbreviated as BLDC motor, is an electric DC motor where the rotation of the rotor is routed electronically. This engine has copper coils placed on the stator and its rotor contains a series of permanent magnets (figure 2). Brushless DC motor is powered by three different waveforms that generate a magnetic field in the stator. The switching of the electromagnetic fields required for the rotation of the rotor is controlled by means of an electronic circuit with a controller.

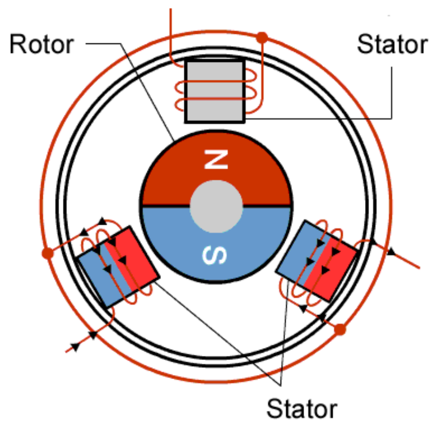

Fig.2. Brushless DC mottor

Advantages of the DC brushless motor:

- The main advantage is a "without sparkle brushes" switching, which at the brush dc motor is a distortion factor of the power system
- Lifetime is significantly higher in relation to the motor with collector, where graphite brush wear limits life and generates periodic service problems.
- The lack of electromechanical device, collector and brushes, removes the limitation of the maximum speed dictated by the heating of the brush that occurs on the DC classical motor.

Position of the rotor

In order to perceive the actual position of the rotor in motion and the number of rotations per time unit (speed), is various methods such as Hall sensors, optic sensors placed on the stator or switching sensorless metod.

Switching sensorless metod

For the switching sensorless metod of the current sense, the actual position of the rotor is perceived using the counter-voltages induced in the stator coils, which are taken over by the control and electronic control circuit and then processed. However, in order to be able to use the voltages, it is first necessary for the rotor to reach a certain speed and, therefore, starting this type of switching sensorless motor is made without control of the position (plastic expressed "blindly"), at as with classic synchronous motors.

In the paper there is presented a control system for a brushless DC motor with Hall sensors and power supply up to 400V.

2. THE PROPOSED SYSTEM

To function, a brushless DC motor with sensors needs a command system that reads Hall sensors located on the stator. They are positioned according to the motor version (number of coils and number of magnets) to refer to the magnetic field with a 120 degree phase shift.

Each change of sensor states will initiate a new command for the three windings according to the direction of rotation desired. To adjust the speed of such an motor, the three windings will be fed with the PWM signal according to the desired speed. The speed will be calculated based on the signals from the existing Hall sensors and the motor design characteristics.

A complete control system will include both the voltage and current measuring circuits. Generally, supply voltages are in the order of 10-50V, but more and more brushless motors are being used with supply voltages of hundreds of volts. The system proposed in the paper is one that can connect any brushless motor with nominal voltage up to 400V. At these voltages the main problem is the galvanic separation of the power part from the control side.

Also, for motors with high poles and speed, the control sequence changes very quickly. A usual used controller is not enough to measure circuit parameters (voltage, current, speed) and to implement a speed regulation algoritm.

For this reason, the proposed system is one made with two controllers, one slave and one master. The slave controller performs only the control sequence required for brushless motor operation depending on the rotor position relative to the 3 Hall sensors. The master controller measures the circuit parameters, implements the control algorithm by providing a slave controller reference PWM signal and performs the interface with the operator. The block diagram of such a system is shown in Figure 3.

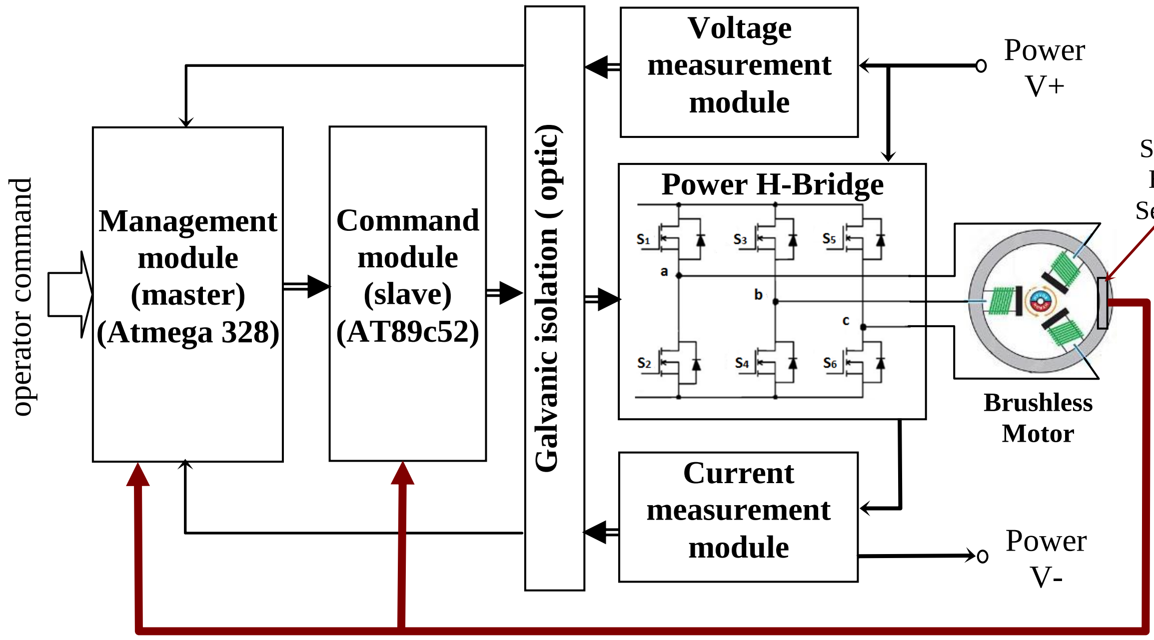

Fig.3. System block diagram

The operator can give commands to start, stop, change the direction of rotation, set the speed value.

The current measurement is implemented with a hall effect current sensor ACS 713 with a maximum current of 30A. There are Hall effect sensors and much larger currents. Typical applications [1] for ACS713 include motor control, load detection and management, switch-mode power supplies, and over current fault protection. The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging. The internal resistance of this conductive path is 1.2 mΩ typical, providing low power loss. The terminals of the conductive path are electrically isolated from the signal leads. This allows the ACS713 to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques. The circuit diagram of the ACS 713 circuit is shown in figure 4.

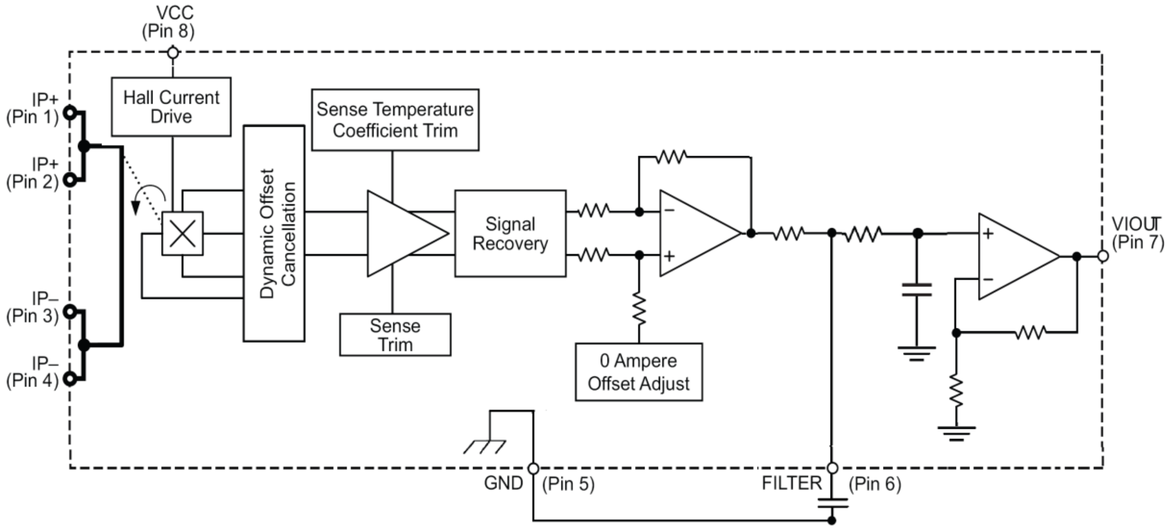

Fig.4. ASC713 current sensor

For the voltage measurement, the voltage to frequency conversion solution was adopted, which is easily galvanic isolated using an ordinary optocoupler. Schematic of voltage to frequency converter circuit is shown in figure 5 and is based on the integrated LM311 circuit. The resistive voltage divider generate a signal up to a 10V wich is applied to the input of the frequency conversion circuit. The output frequency will be given by the formula:

$$f_{OUT} = \frac{V_{IN}}{2.09\ V} \bullet \frac{R_S}{R_L} \bullet \frac{1}{R_t C_t}$$

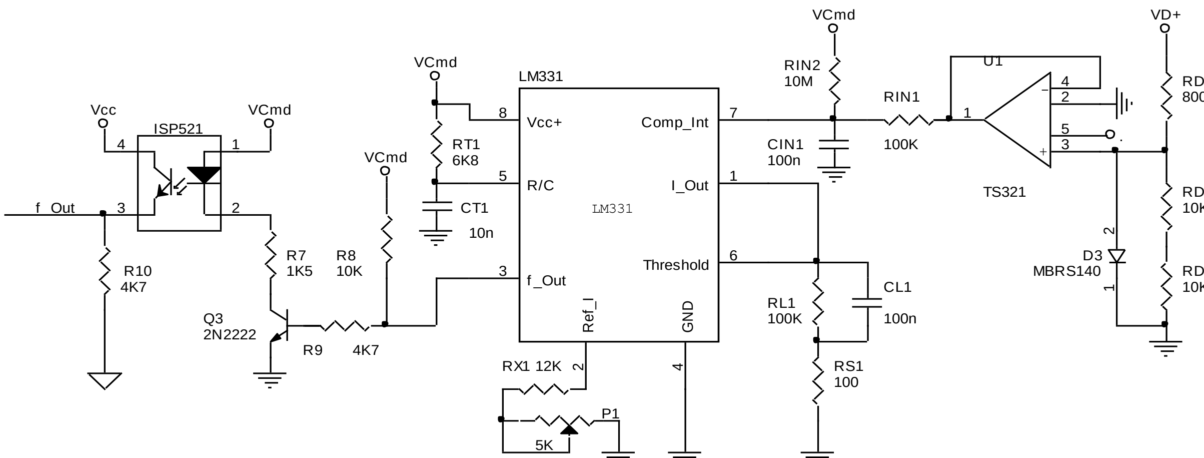

Fig.5. Voltage to frequency converter

System operation

The slave controller receives information from the master controller about the direction of rotation as well as Start / Stop commands.
The slave controller reads the position of the rotor according to the 3 Hall sensors and will generate 6 control signals for a 3 phase h-bridge, fully-controlled, depending on the received commands. The commands to be applied to the h-bridge, depending on the rotor position, are modulated by a reference PWM signal received from the master controller in order to adjust the motor speed to the default value of the user.

The master controller reads the supply voltage and motor current to provide various protection. It reads signals from Hall sensors to determine motor speed and generates a PWM signal for speed control based on a control algoritm (usually PI). All of these master controller tasks require relatively high processing time over bridge commnad times.

Therefore, it was preferred to use two common controllers (At89S52 and Atmega328) instead of a single processor with high computing power but also with greater complexity.

The power circuit was accomplished with MOSFET transistors for which the IR25606 specialized drivers were used to control the low and hight side of a H-bridge.

The IR25606 is a high voltage [2], high speed power MOSFET and IGBT driver with independent high and low side referenced output channels. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600V.

System implementation and test connection of a hoverboard motor powered by a 40V voltage source is shown in figure 6 left. The motor used is one that has a number of 27 coils and 30 magnets and is prevented in figure 6 right.

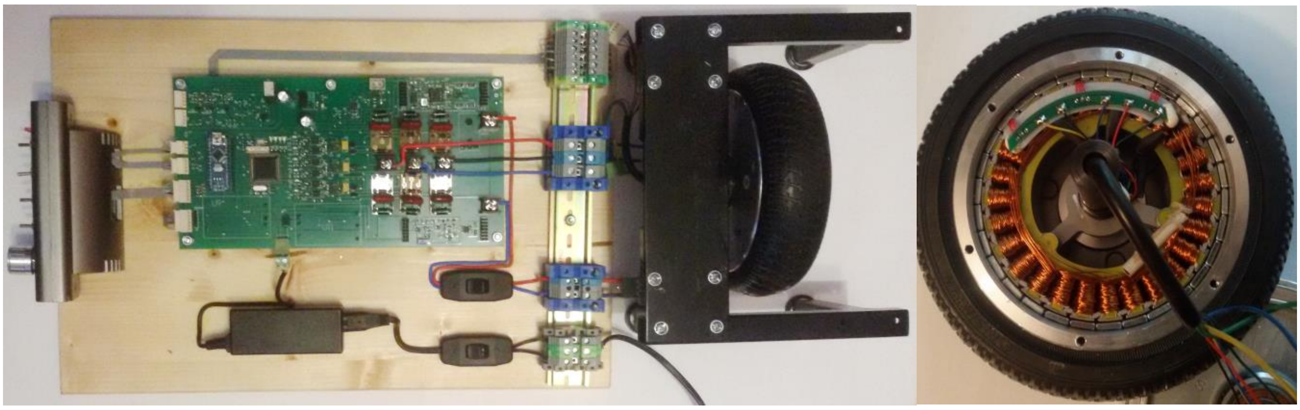

Fig.6. Brushless DC motor control system

The slave controller will read from hall sensors six distinct states. A Hall sensor will read a magnet during three distinct states depending on the rotor position. This results in a total of 30x3 = 90 commands needed to perform a complete rotation. At a speed of 1500 rotations / minute, the order is changed every 445μs.The period is large enough to implement a command but not enough to achieve protection or a speed adjustment algorithm. There are brushless motors at which speed can be over 10 times as high as 20,000 rotations per minute. In this case, the time for each command drops considerably. To achieve a system that can also be used for controlling high speed brushless motors, the system solution with 2 controllers one for command (slave) and one for management (master) was chosen.

After implementing the system and testing it, the following problem occurred. As a result of the repeated execution of some break-off commands by connecting the three motor windings to the ground, some transistors have failed to act as a short circuit. Although the power supply voltage of the force part is only 40V at a maximum current of 5A, a 400V and a 60A MOSFET transistors have been damaged . This was due to overvoltages resulting from rapid switching of currents through coils. To verify this phenomenon was simulated the control of a h-bridge having at load an magnetic circuit (the primary of a transformer having a secondary resistive load). As a result of the simulation, self-induced voltages on the transistor's DS junction were obtained that exceeded the 600V maximum permissible VDS in the catalog sheet. To limit these effects, spike voltage limiting circuits as well as Transil protection diodes have been used. Figure 7 shows the simulated circuit having a protection circuit only in the high side of bridge

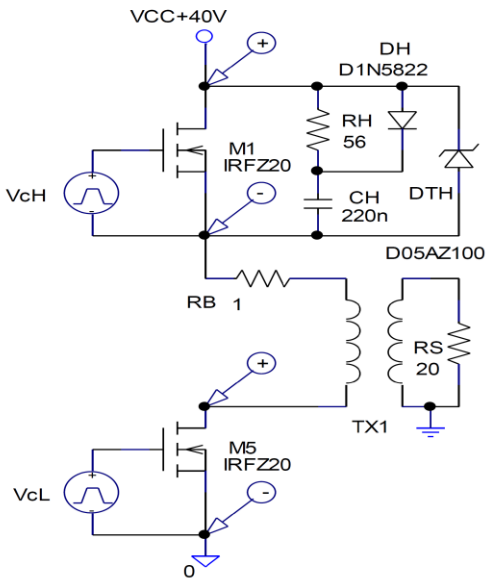

Fig.7. Simulated circuit

Transil diode [3], (Transient-voltage-suppression diode) is an avalanche diode specially designed to clamp over voltages and dissipate high transient power. The Transil diode feature is similar to a Zenner diode but with the exception that the Transil diode can handle very high currents of tens of amps but for a short time (hundreds of microseconds). A Zenner diode of 100V was used for simulation and the result is shown in figure 8 We notice the drop of the voltage peaks to the values allowed by the transistors used.

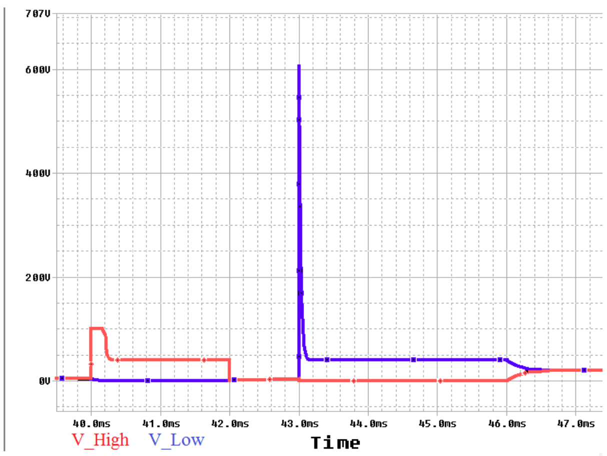

Fig.8. Simulation signal

As a consequence of the implementation of the protections and circuit testing at break-off commands for a large number of times no transistor has been damaged.

3. CONCLUSIONS

For the speed reference, a voltage signal obtained from a potentiometer was used but a voltage signal with the 0-4V operating range can be used. The control buttons are Sens, Start/Stop and Break. The difference between the Stop command and the Break command is that at the Stop command the motor receives the speed down command until it stops while Break command the botor stops suddenly by connecting the motor windings to the ground.
To avoid strong shocks, the change of direction command is done by lowering the motor speed to the stop and then accelerating in the desired direction. Startup is also done by software by gradually increasing the speed to the desired value.
The implemented system can be used to control a wide range of brushless motors with Hall sensors. There is also the possibility of implementing serial communication both to control the motor's operation and to parameterize the management function.

4. REFERENCES

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