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SENSORLESS SMALL PERMANENT MAGNET BRUSHLESS MOTOR DRIVES

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***Abstract* – The sensorless drive of a brushless motor involves the position estimation of the rotor, without Hall sensors to generate the switching signal. For this reason we need to detect the commutation points. We are studied the currents and phase-to-phase voltages for a small brushless motor. The currents are sensed with current sensors (LEM). A virtual instrument developed in Lab View visualisates the currents and voltages and determinate the commutation points. This is connected to an other VI witch generate the switching signal. In our case the small BLDC is drive in frequency control mode, that means the current impulse has constant T_{on}/T ratio and variable frequency. The mean value of the current depends on frequency. The developed VIs are able to drive the small BLCD motor.**

Keywords: *brushless motor, virtual instrument, sensorless motor drives.*

1. INTRODUCTION

The brushless motors comprise 3 main elements: the fixed part, the stator, has three groups of coils, the three phases of the motor. These coils operate as electromagnets and generate various orientations of magnetic field regularly distributed around the central shaft of the motor. The rotating part, the rotor, has permanent magnets. These magnets permanently drive the rotor to try to align itself with the magnetic field of the stator. Generally the rotor is mounted on ball bearings [1].
The three "Hall effect" magnetic sensors, placed at 60 or 120-degree intervals, provide information on the position of the rotor magnets at all times. The electronics deduce from the sensors the orientation of the rotor and adjust the orientation of the field to the position of the rotor, in order to drive it in the chosen direction, that means generate switching signals for the six transistors in the drive circuit (fig.1). Varying the current in the coils, the electronics can accelerate or slow down the motor and thus regulate its speed. They can also orient the magnetic field in order to break the movement of the rotor to bring it to a standstill.
Brushless DC motors are supplanting conventional motors like induction motors, brush DC motors and stepping motors to become the major actuator in mechatronics because of its simple construction, reliability and energy-saving characteristics. The brushless DC motors are extensively employed in robots, information devices, medical equipment, home appliances (air conditioners, refrigerators, washing machines), and industrial applications (pumps and ventilators) and other areas [2].
The motor is controlled by PWM (Pulse Width Modulation), but it can be controlled in frequency mode. In PWM control mode the mean value of the current depends on the ratio Ton/T of the pulse trains of fixed frequency. At constant angular speed the torque is directly proportional to the current.

$$P_m = m\omega = (m_a + m_b + m_c)\omega = \\ = u_a i_a + u_b i_b + u_c i_c \qquad (1)$$

The torque has to be without pulsation. To obtain this at first we need to determinate the voltage proper to the magnetic field. Then we have to determinate the current that way that its product with the voltage to be constant [3].
In frequency control mode the current impulse has constant width and variable frequency.
The small brushless motors (<100W) are simplifying version of the permanent magnet synchronous motor for high torque operation.

2. BLDC MOTOR DRIVE SOLUTION

Sensorless techniques have a few advantages: reduced component, improved reliability, eliminates mechanical and hysteresis problems of discrete sensors, simple algorithm. At brushless DC motors the sensorless technique involve back-emf zero crossing detection, third harmonic voltage detection. But exist some problems too, sensitive to parameter variation, poor performance at low speed, initial position not identifiable.
In this case a small brushless DC motor is studied. This small brushless motor (from a CDROM) has no sinusoidal *emf*, peak phase current 0.3A, phase voltage 10V and in frequency control mode f_{max}=2500Hz.
Figure 1 shows the block diagram of the connection between the small brushless motor and data acquisition and control system, realized in Lab View 8.2 with PCI-6221 card.
A linear multiplying scale was established at the acquisition of the phase current, to follow the current and the voltages of the same graph.

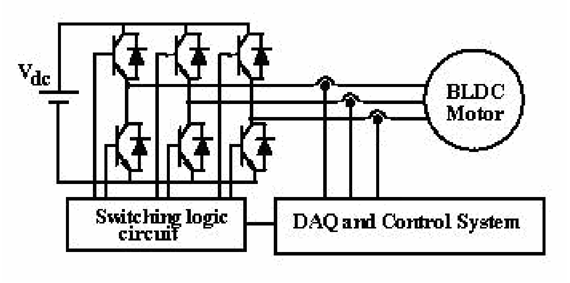

Figure 1: Brushless DC motor drive system.

The motor is controlled through an inverter, used ¾ part of a dual full-bridge (L298). The switching logic circuit is realized with multiplexers, 74LS151 type. These multiplexers distribute the switching impulses in the right order to the inputs of the L298 dual full-bridge (pins 5, 7, 10). It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads. Two enable inputs are provided to enable or disable the device independently of the input signals. Because we use ¾ part of the dual full-bridge the enable inputs are connected to high level. The external sensing resistor is common also. The BLCD motor's phases are connected to the power outputs (pins 2, 3, 13). An external bridge of diodes is required at power outputs when inductive loads are driven and when the inputs of the IC are chopped; Schottky diodes would be preferred.

The switching logic circuit receives the impulses from the control system realized through the second VI.

2.1. Commutation Points Detection

The sensorless drive of a brushless motor involves the position estimation of the rotor, without Hall sensors, to be able to generate the switching signal for the proper transistor.

For this reason we need to detect the commutation points.

First we have measured and visualized the currents and the phase-to-phase voltages for the motor, to compare the commutation points and to determine the relation between variations of these.

Figure 2 presents the currents and phase-to-phase voltages for the studied small brushless motor.

As it can be seen the phase-to-phase voltage between a phase and b phase change abruptly from negative values to a positive values, exactly at the point where the commutation point of phase c is. The same happens in the case of the other two phases too. Because the changes of these voltages are not measurable, we follow the phase currents. The currents are sensed with current sensors (LEM).

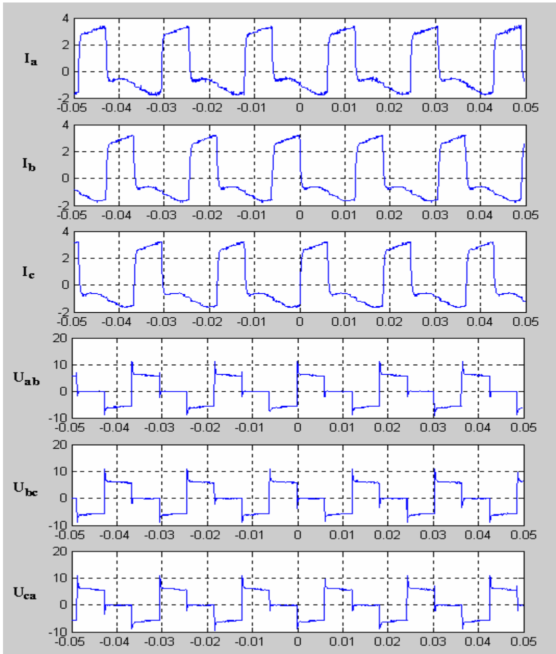

Figure 2. The currents and phase-to-phase voltages for the studied BLDC.

A virtual instrument developed in LabView, visualisates the measured data and determinate the commutation points.

Figure 3 shows the block diagram of this VI.

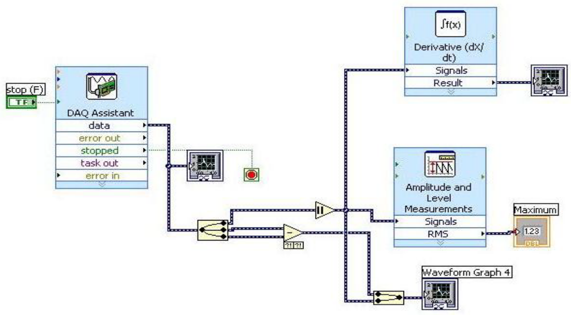

Figure 3. VI block diagram for currents acquisition.

The equation written on the simplified equivalent circuit of the motor when a couple of phases are conducting is:

$$V_{DC} = 2Ri + 2L\frac{di}{dt} + U_{ab} \qquad (2)$$

At constant speed the term 2Ri does not change significantly, and results:

$$\frac{d^2 i}{dt^2} \approx \frac{dU_{ab}}{dt} \qquad (3)$$

The commutation points can be obtained from the slopes of the phase current [4], [7]. This is determinated also by the VI, and generates the clock signal for the switching logic circuit.
Figure 4 shows the phase voltages and current, the phase-to-phase voltages and derivate of the last one, which shows the switching points, measured with the VI.

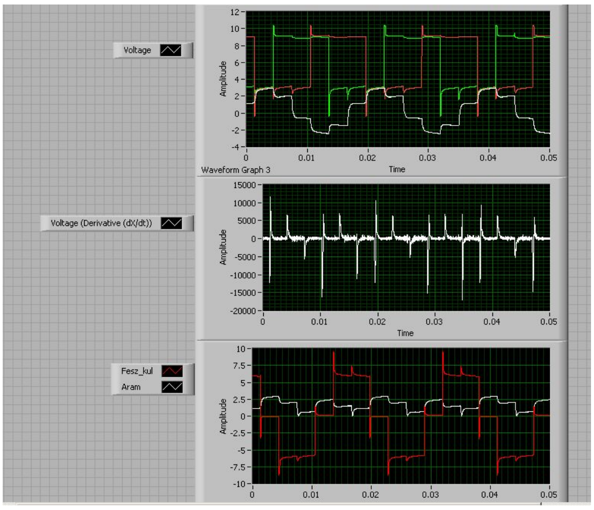

Figure 4. Voltages and currents measured with VI.

In the same way we can obtain the commutation points from the phase currents also. We follow the phase currents with three current sensors (LEM) and the derivate of these indicate the switching points.
Having the switching points, the impulses generated in these moments, are carried out trough the data acquisition card at the output AO-0 and AO-1. These can be visualized with digital oscilloscope.
It is important to mention that at starts of the motor we have no information about the switching points. That's why we have no feedback at the beginning, so the starting is slow.

2.2. Driving Signal Generating

In our case the small BLDC is drive in frequency control mode, that means the current impulse has constant Ton/T ratio and variable frequency. The mean value of the current depends on frequency:

$$I_m = \frac{1}{T}\int_0^{T_{on}} i(t)dt = f \cdot I_0 \cdot T_{on} \qquad (4)$$

An other VI was developed to generate the switching signal. The control systems, which generate the driving signal, uses an external clock at the input PFI0 of the data acquisition card to generate an impulse with constant duty cycle (50%) and frequency depending on external clock.
The external clock signal is given by the impulse from the derivate of the phase current. We compare this external clock signal to the reference signal that determinates the velocity. We can set the reference signal from the front panel of the VI.
At constant velocity the external clock signal and the reference are equal. In this case the control system generates the driving signal and sends it to the switching logic circuit, according to the external clock signal. This driving signal controls the L298 full-bridge transistors.
When the velocity is changing for a short time the driving impulses are given by the reference.
The driving impulses are shifted each from the other with a half width of impulse.
Figure 5 shows the block diagram of this VI. Through the front panel we can select the physical channel at which we obtain the impulse for the switching circuit and the channel for the clock [8].
The speed of the motor is controlled through frequency. To control the small BLDC in PWM mode, we mast complete the VI with proper blocks to change the duty cycle of the impulse according to the I_{ref} or speed.

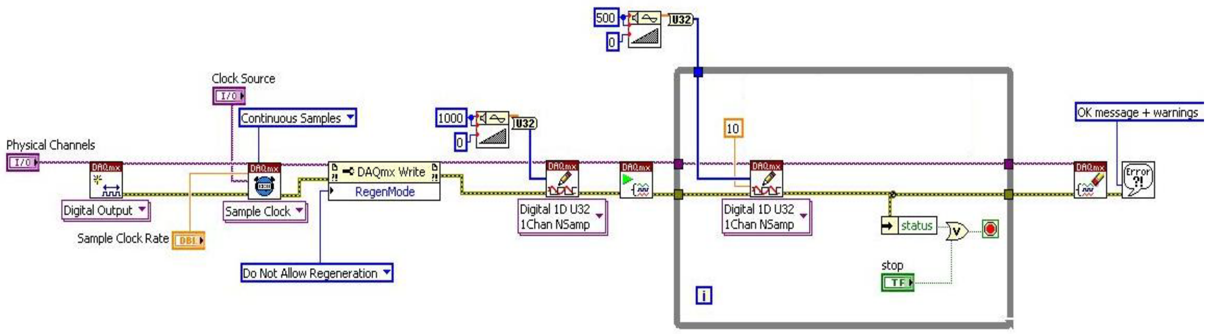

Figure 5. VI block diagram for impulse generation.

First we create a digital output channel to set the physical channel (port0) where we obtain the generated signal.
Then we set the source of the clock (PF10), and the rate of the sample clock, using the DAQmx Timing.vi, which has too important input, source and channel in. The source specifies the input for the external clock. The channel in specifies the output channel for the generated signal.
With the DAQmx Write.vi we send the data to the output.

3. CONCLUSIONS

It was developed a virtual instrument to drive a small brushless DC motor in a sensorless way. With a DAQ and control system we measure the current in three phases of the motor and we determinate the commutation point to generate the switching signals having a constant duty cycle. By this time the control mode is a frequency one. The position of the rotor can be estimated by detecting the zero crossing of all the phases' currents and approach the negative parts with a linear model also. In this case the commutation points were detected from the derivate of the currents.

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References

[1]. Crouzet, Basic Concepts.Brushless motors and geared motors. www.crouzet.com

[2]. Tatsuya Kikuchi, Takashi Kenjo, Shuichi Fukuda, Remote Laboratory for a Brushless DC Motor.

[3]. Schmidt I., Vincze Gyuláné, Veszprémi K., Villamos szervo- és robothajtások. Műegyetemi Kiadó, 2000.

[4]. Juan W. Dixon, Matías Rodríguez, Rodrigo Huerta, Simplified Sensorless Control for BLDC Motor, Using

DSP Technology.

[5]. Enzo Chiricozzi, FrancescoParasiliti, Roberto Petrella, Marco Tursini, Sensorless permanent Magnet

Synchronous Motor Drive Solution for Compressor Application.

[6]. D.Howe, Z.Q.Zhu, Sensorless PM Brushless Drives. IEEE UK Chapter Seminar, 2003.

[7]. Juan Dixon, Matías Rodríguez, Rodrigo Huerta, Position estimator and simplified current control strategy

for brushless-dc motors, using DSP technology.

[8]. *** User Guide for LabView, National Instruments, 2006.