

MICRO-STEPPING COMMAND OF HYBRID STEPPER MOTORS USED FOR ELECTRODE TOOL DISPLACEMENT OF SINKING EDM-MACHINES

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ABSTRACT: In the first part of this article, the authors make a short presentation of electrode tool displacement control system for sinker electrical discharge machining. The advantages of stepper motor used in kinematics chain are also mentioned. In the second part, the authors compare the principal type of current control trough the coils of the two phase bipolar stepper motors: wave, full step, half step, 1/4 micro-stepping uniform subdivision, 1/4 micro-stepping sin-cosine subdivision and make an intuitive presentation. The peak current limiting principia are showed in the third part of the article for circuit realised with digital and analog circuits. A conceived electrical schema used for Pspice simulation is also presented. The results of simulation confirm feasibility. An electrical schema for sine-cosine drive of bipolar stepper motor has conceived with digital and analog circuits which have been simulated. In the fourth part of this paper, the authors summary present principle of peak current control using digital signal controllers. Two physical drive modules were conceived and realised using DSC and measured current chronograms were presented.

KEY WORDS: sinking electrical discharge machining, servo feed control, micro-stepping, peak current control

1. INTRODUCTION

In electrical discharge machining (EDM), pulsed arc discharges occur in the gap between electrode tool (ET) and work piece (WP). The gap is filled with an insulating medium, usually a dielectric liquid like hydrocarbon oil or de-ionized (de-mineralized) water. In sinking EDM process, the electrode shape is copied with an offset equal to the gap size ($g = 10 - 100 \mu\text{m}$) [3, 4].

A small gap creates conditions for short circuits and a large gap doesn't create conditions for ignition (open circuit) or the delay time (t_a) between the moment of high voltage applications and the moment of discharge apparitions is too long.

For assures a proper delay, which implies a good productivity, electromechanical system for displacements of electrode tool must have a forward movement (when the gap is too large), a reverse movement (when the gap is too small) and no displacement when the gap is proper. The stepper motor has behaviour adequately for these requirements [4].

Figure 2 shows the chronograms of voltage pulses applied to the gap and the current in normal conditions. Figure 3 shows the principle of servo feed control and figure 1 shows Z-axis subsystem (for electrode tool displacements) realized with bipolar stepper motor. For the state of the gap characterisation, only information about the voltage (u) is sufficient in many types of control. For low complexity machines, average voltage obtained by resistive voltage divider followed by an analog integrator, which commands a DC motor was usually used. For the many controllers, ignition delay time (t_a) is used to determining direction of movements for electrode tool like principle showed in figure 3.

For complex machines, a computer based controller determines ignition delay time (t_a) and other gap's parameters like evolution of pulses parameters, for improving performances of control [4].

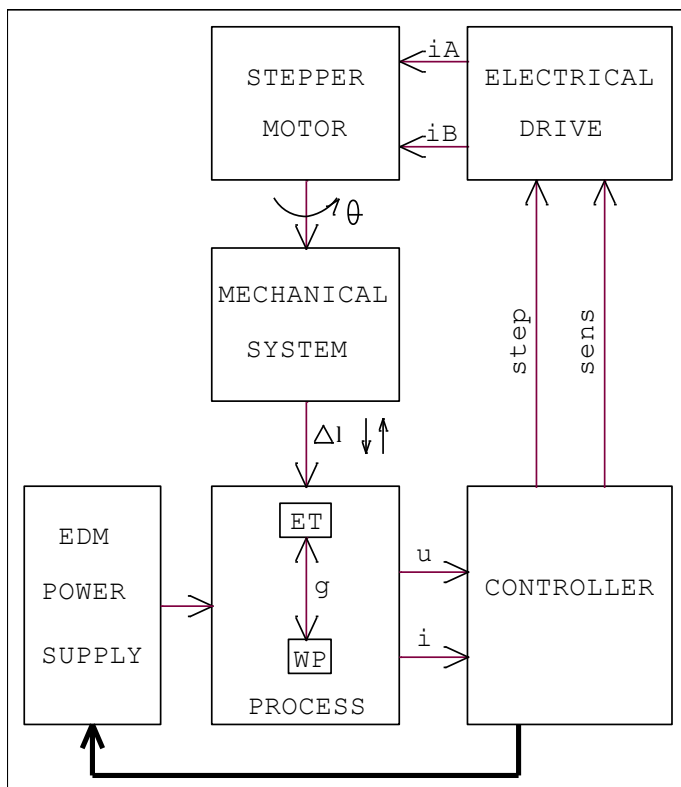


Figure 1. Sinking electrical discharge machine: Z-axis subsystem (with bipolar stepper motor) and power supply (which includes pulse generator)

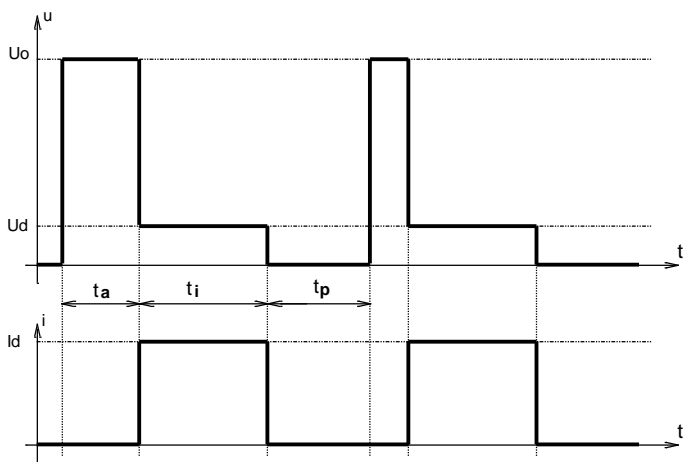


Figure 2. Simplified chronograms of gap voltage and current for normal discharges

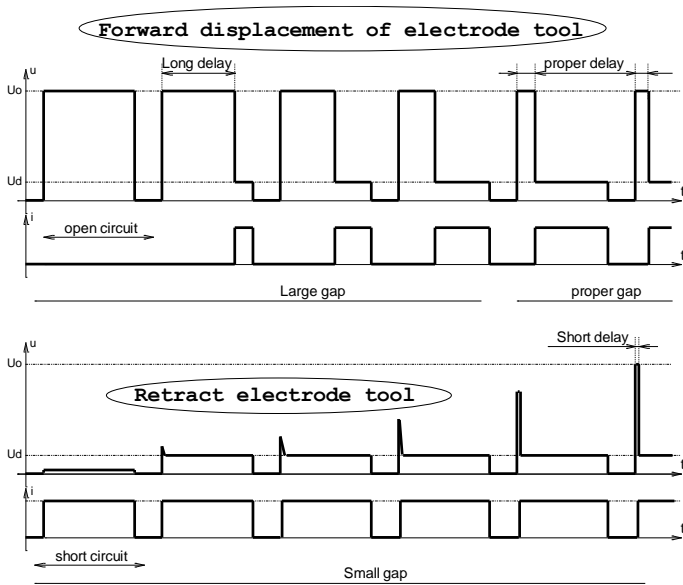


Figure 3. Principle of servo feed control (idealized chronograms)

For EDM power supply with controlled current of pulse generator, the current sensing is necessary. That increases the complexity of electrical circuit, especially if short time of pulses duration is necessary. The controller assures commands for pulse generator and for electrical drive too, like it is showed in figure 1. A correlation between commands is necessary for reduction of short circuits time.

2. TYPES OF COMMAND FOR BIPOLAR STEPPER MOTOR

A stepper motor used in electrode tool displacement system has some advantages in comparison to the other types of motors:

- Possibility to assure correlation between incremental functionality of motor and discrete character of process evolution.
- Possibility to memorise the position by electromagnetic break after the last pulse applied to the motor.

- Rapid change of revolution's direction.
- Simplified of cinematic chain with a good resolution for linear displacement.

The most used type of stepper motor is the hybrid motor, which is a constructive combination between the permanent magnet stepper motor and variable reluctance stepper motor.



Figure 4. Hybrid stepper motor - disassembled view

For experimental set, a so called "eight wires" stepper motor was used. This can be configured as unipolar or bipolar connection. Bipolar connection assures high speed for current modification through the motor coils (both for increase and decrease of the current value) by using a high voltage of power supply ($V_{alimentare}$) and two H-Bridges. In this case, a current limiting technique is necessary [5].

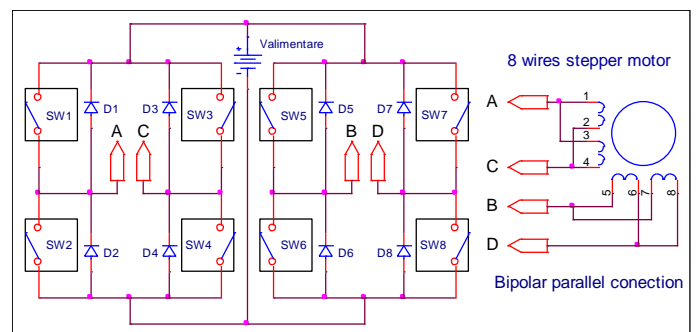


Figure 5. Bipolar parallel connexion for eight wire stepper motor and their driver with two H Bridges

Looking at the figure 5, for power supply which has a nominal voltage given by equation (1), a positive nominal value for current through phases A-C assures for switches SW1, SW4 in "ON" state and switches SW2, SW3 in "OFF" state.

$$V_{alimentare} = I_{motor} \cdot R_{motor} \quad (1)$$

For motor used in experimental set which has $R_{motor}=1.1 \Omega$, $I_{motor}=3 \text{ A}$, $V_{alimentare}=3.3 \text{ V}$ results.

For simplified permanent stepper motor, the states of motor coils and chronograms of current for wave command are showed in figure 6. Red color for wire suggests the north magnetic pole, blue color suggests the south magnetic pole, and black color suggests an inactivated coil. The other types of command are showed in the next figures. For microstepping, high value for $V_{alimentare}$ and current limiting technique is necessary [1] [2] [3].

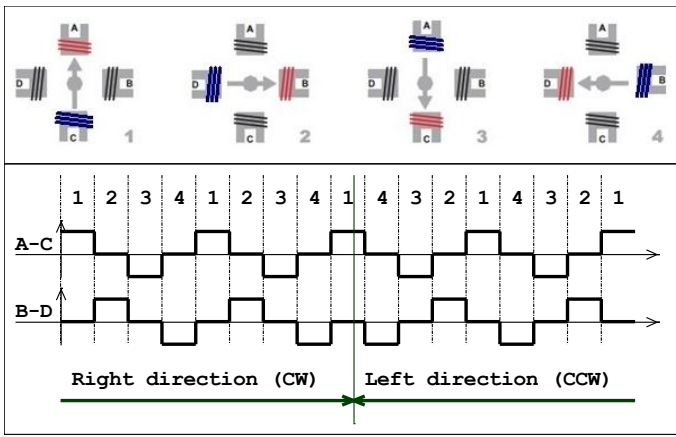


Figure 6. Wave drive: the states of motor's coils and current evolution

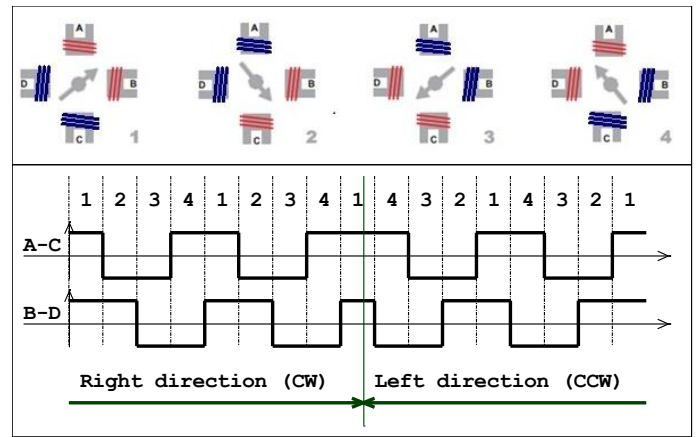


Figure 7. Full drive: the states of motor's coils and current evolution

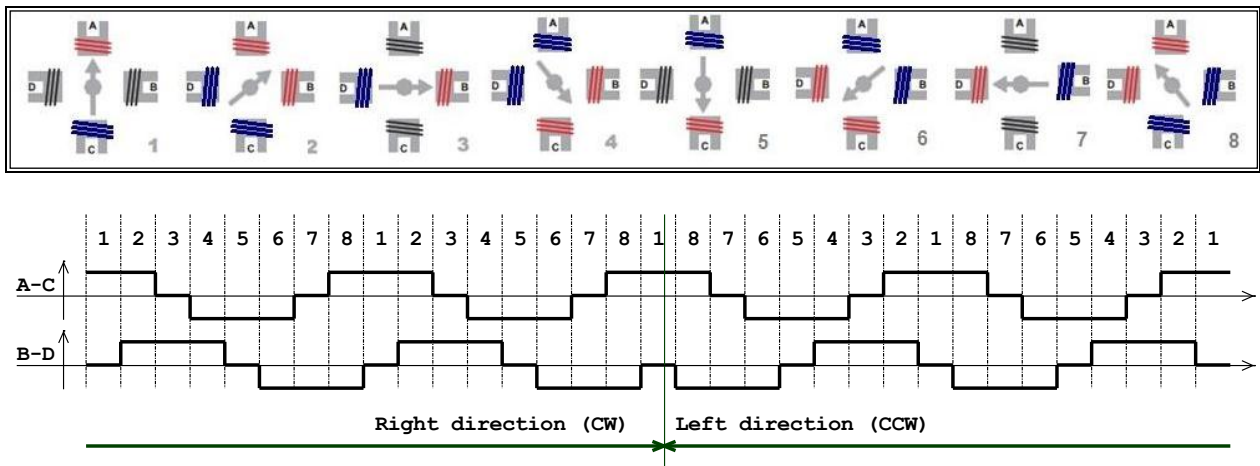


Figure 8. Half step drive: the states of motor's coils and current evolution

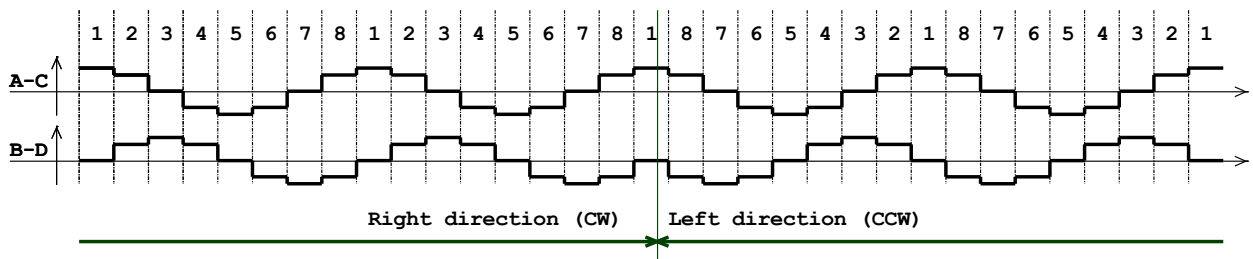


Figure 9. 1/2 micro-stepping sin-cosine drive: the evolution of current through the motor's coils

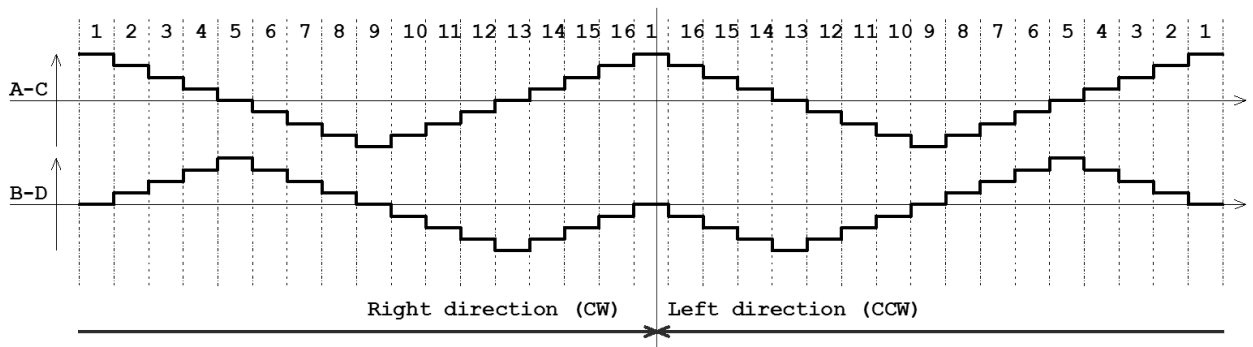


Figure 10. 1/4 micro-stepping linear drive: the evolution of current through the motor's coils

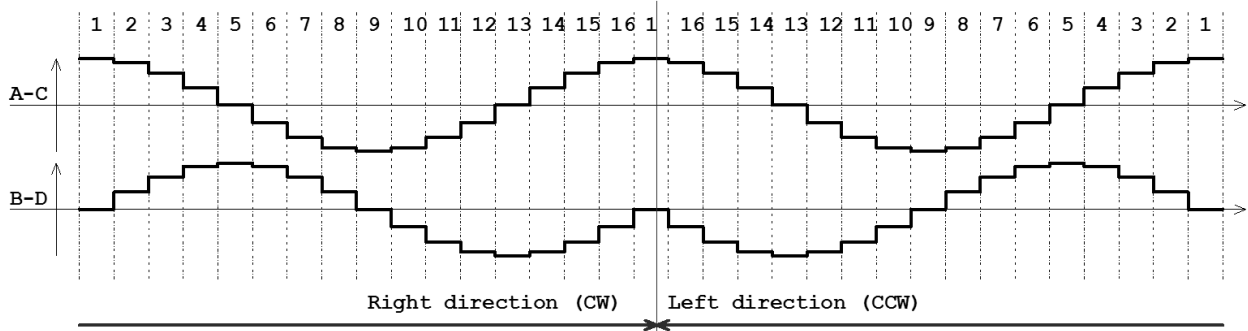


Figure 11. 1/4 micro-stepping sin-cosine drive: the evolution of current through the motor's coils

For simplified permanent magnet stepper motor presented above, the magnetic force is constant in every state for sine-cosine drive. Maximum of force is obtained in full step command and minimum in linear command.

3. PEAK CURRENT CONTROL

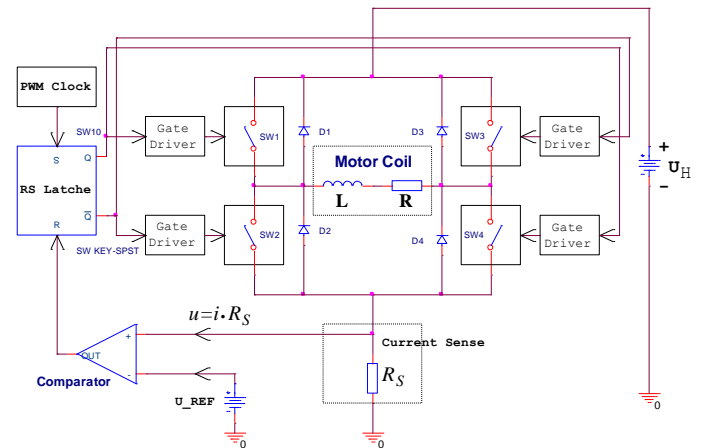


Figure 13. Peak current limiting principle schema for one phase of bipolar stepper motor

In figure 14, it is showed the principle schema to limit current through the motor coil, using digital and analog circuits. The current sense resistor gives a voltage proportional with the current through the motor coil. This value is compared with the reference voltage. When the current exceeds a maximum imposed value, the output of analog comparator resets Latch, the output Q becomes zero logic, the PWM pulse is finished and switches SW1, SW4 is turned "OFF" and switches SW2, SW3 is turned "ON". The voltage applied on the coil inductance becomes negative (approx $-V_H$) and current through the motor coil becomes decrease.

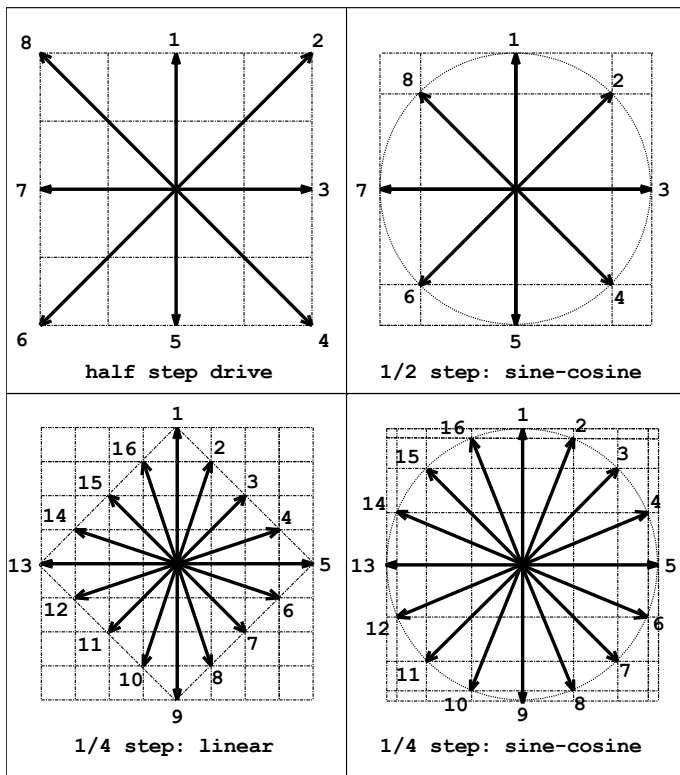


Figure 12. Synthesis of magnetic force in every state for different types of drives

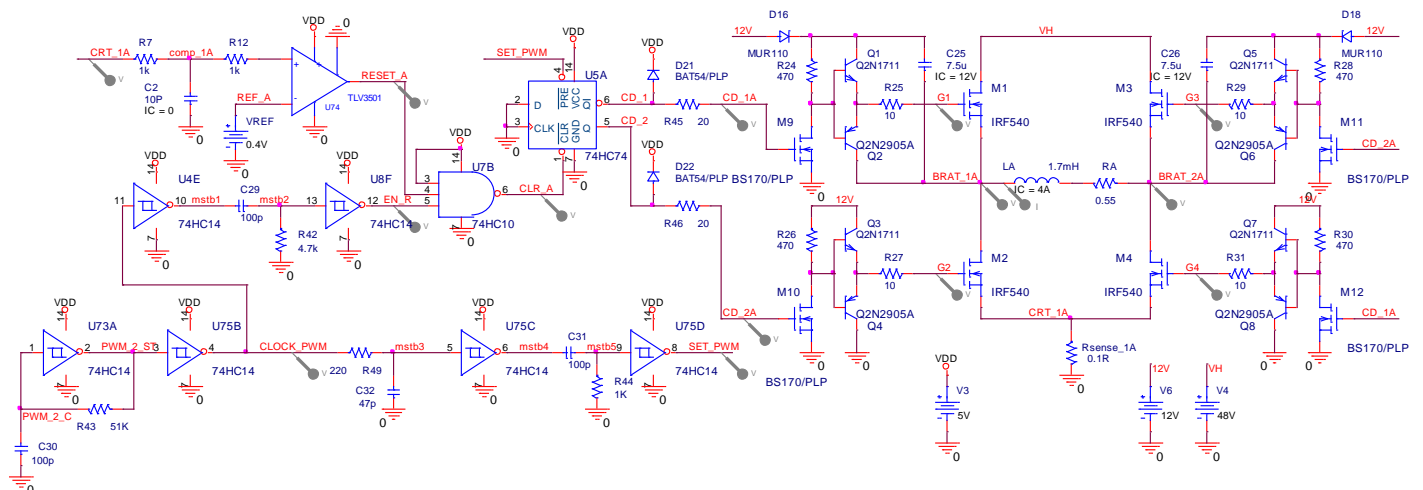


Figure 14. Electrical schema, used in OrCAD - Pspice simulation for highlighting the peak current limiting principle

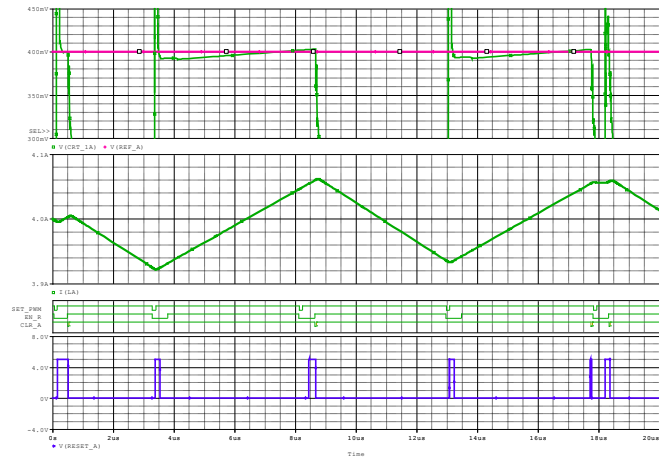


Figure 15. Chronograms results from simulation

The authors was conceived an electrical schema which is presented in figure 14. By electrical simulation in Orcad Pspice, the chronograms showed in figure 15 result. In central plot, we can observe the evolution of current trough the motor coil. The motor coil was emulated by an inductance in series with a resistor, back electromagnetic force doesn't appear, but errors are negligible. Modifying the value of reference voltage (VREF), applied to the analogue comparator TLV3501, determines the modification of average value of current trough the motor coil. A complete schema, shoved in figure 16, was conceived for simulation sine-cosine motor command and results are presented in figure 17 [5].

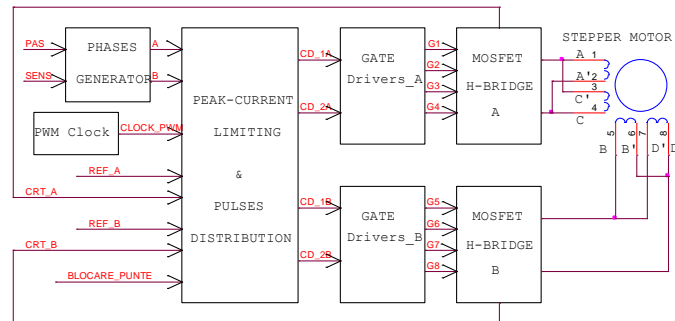


Figure 16. Block diagram of conceived bipolar motor driver schema for electrical simulation

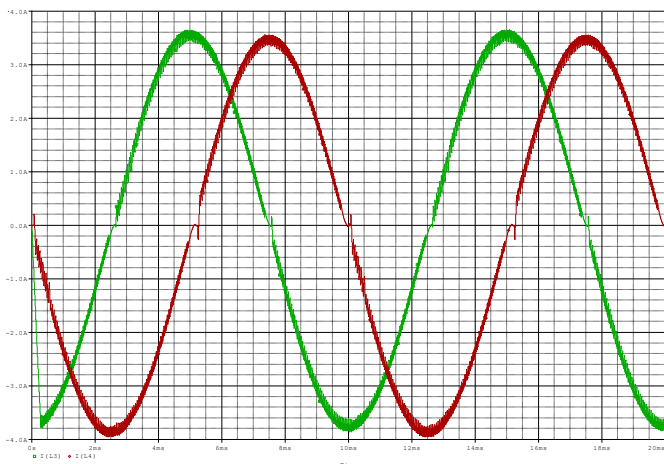


Figure 17. The evolution of current through the motor's coils gives by electrical simulation

4. PEAK CURRENT CONTROL USING DIGITAL SIGNAL CONTROLLER

Spectacular evolution of semiconductor's technology and microelectronics was bringing to apparition of the very complex circuits which include analog and digital functions. Microcontroller is a computer on chip, which includes digital processing functions and peripheral blocks. Digital Signal Controller (DSC) has supplementary facilities to assure digital control in motor drive and switching mode power supply. Peak current limiting technique is easy to realise with DSC as showd in figure 18. A physical prototype was realised and sine cosine drive for stepper motor was performed [6].

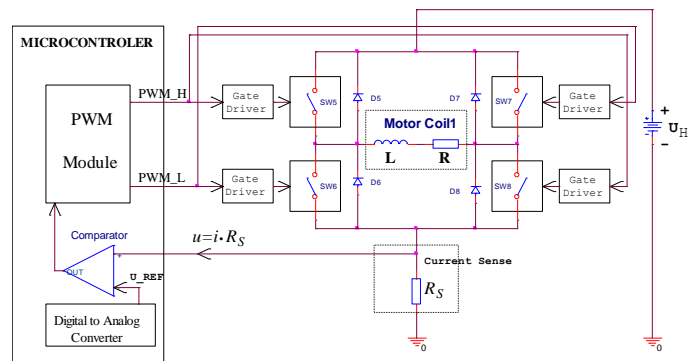


Figure 18. Peak current limiting principia schema for one phase of bipolar stepper motor, using DSC with integrated analog comparator

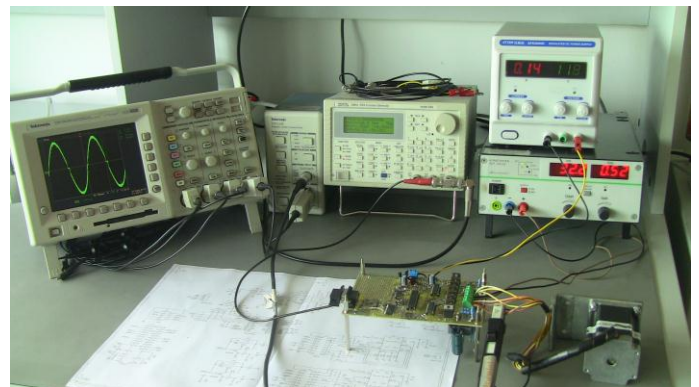


Figure 19. Experimental set up with realized prototype

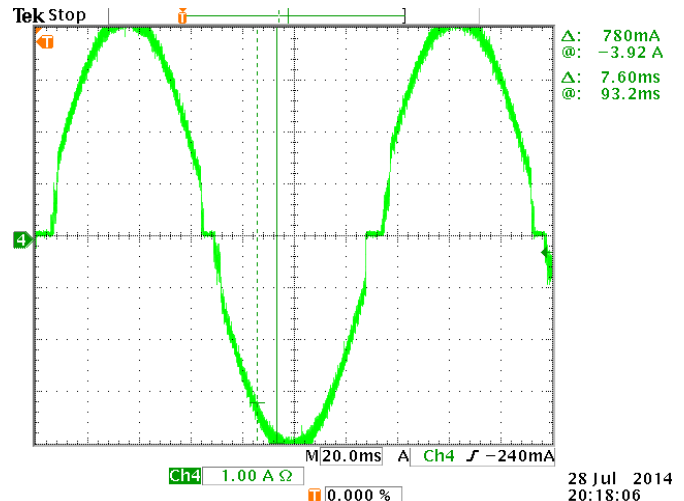


Figure 20. The evolution of current through the motor's coils gives by experimental results for 1/64 step sin-cosine drive

In figure 20 we see a "dead" interval at zero crossing for current. By splitting the current sense resistor, for every leg of bridge, this problem can be diminished. Another way to improve the sinus accurate is to put the current sensor in series with motor coil. For reducing the ripple of current trough the motor coil, it is necessary to have a high frequency of Pulse Width Modulation (PWM), above 100 KHz [7]. Hall effect sensors are the best option for frequency under 50 KHz. For voltage of motor power supply (V_H) under 60 V, integrated circuits AD8210 can be a good choice.

Another prototype was realised, the drive and current sensing for one coil is presented in figure 21. Unfortunately, for switching of leg Brat_1A of H-Bridge, a perturbation during approx. 1.5 μ s is presents on the sensor output CT1_OUT.

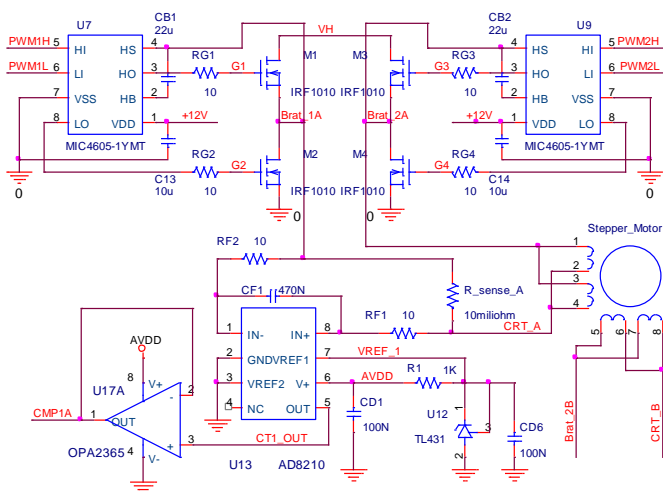


Figure 21. NMOS H-Bridge with gate drivers and current sensing based on AD8210 integrated circuit.

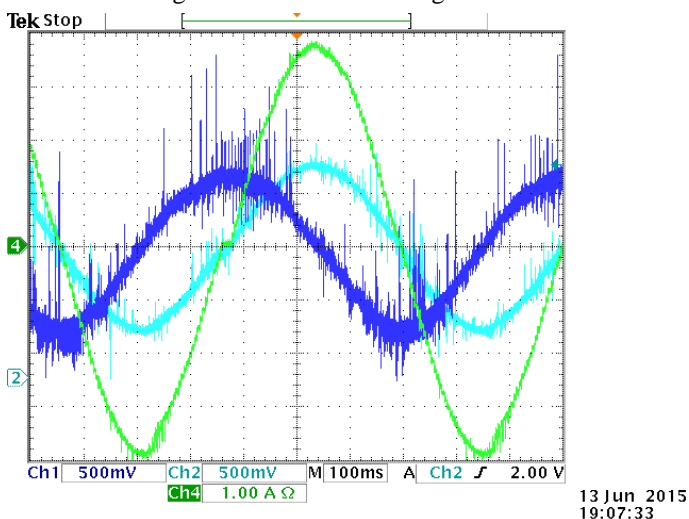


Figure 22. The evolution of current through the motor's coils given by experimental results for 1/32 step sin-cosine drive and 320 KHz PWM frequency.

For this reason, the gate drive for NMOS transistors M1 and M2 was modified by adding a DC-DC converter to supply CB1 (Bootstrap capacitor) and

M1 is permanently "ON" for positive current, M2 is permanently "ON" for negative current. In figure 22, output voltage of current sensors is showed on CH1 and CH2 and current trough the coil B is showed on channel CH4. The Printed Circuit Board (PCB) requires a careful design for reducing the noise (generated by NMOS transistors switching) and reducing the noise sensitivity of analog part.

5. CONCLUSIONS

Full step command of stepper motor for electrode tool displacement is easy to implement, but mechanical oscillation at low frequency is a major impediment. Microstepping command reduces the smooth and eliminates mechanical oscillation. Using a high voltage for motor supply, the maximum speed of motor increases significantly and displacement is more precise. High frequency of PWM switches command and high performance current sensor is necessary for accurate sine-cosine drive.

6. REFERENCES

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