IMPROVING OF STEPPER MOTOR BEHAVIOUR USED ON CINEMATIC CHAIN OF MACHINE-TOOLS FOR ELECTRICAL DISCHARGE MACHINING

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ABSTRACT: In this paper is presented the design of a power interface for stepper motor control, used in electrode tool displacement system for Electrical Discharge Machining and Industrial Robots. Using the current limiting technique, for high torque bipolar stepper motor, a reduction of the current rise time and the fall time was obtained. In this case, for full step mode, the maximum speed of stepper motor was increased significantly. The project was developed around a 16 bit modern microcontroller. Using a pulse width modulation technique, and a current control, a microstepping motor control was obtained. In this case the minimum displacement for electrode tool was reduced. A physical prototype was realized and some experimental measurements are presented.
KEY WORDS: Stepper Motor, Wired Logic Simulation, Microcontroller, Current Control, Micro stepping.

1. INTRODUCTION

The Stepping motors can be considered as electric motors without switches. All windings are part of the stator, and the rotor is either a permanent magnet. All of the commutation must be handled externally by the motor controller, and the motor and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other. Most steppers can be stepped at audio frequencies, allowing them to spin quite quickly, and with appropriate controller, they may be started and stopped “on a dime” at controlled orientations [1] [5].

Using a stepper motor is possible to design applications in simple open-loop control system. In this case mechanical actuated system, have low accelerations with static loads. This case can be seen in many examples of cinematic chain of machine tools, Electrical Discharge Machining and Industrial Robots.

A stepper motor requires a signal generator and a pulse distributor power static switching. Stepper motor haves the advantage of producing high torque at low speed. Stepper motor haves holding torque which allows keeping its position firmly when not turning. Holding its position is useful for intended application where the motor will be starting and stopping. In this time the force of the mirror’s momentum acting against the motor remains present. The results will be unnecessary of brake mechanism. The kinematic chains of Electrical Discharge Machining which provides feed of electrode to adjust working gap are using the stepper motors [2].

2. SIMULATION OF COMMAND AND CONTROL OF STEPPER MOTORS

The stepper motor as the same devices is a torque-producing, and this torque is generated by the interaction between magnetic fields. The driving force behind the stator field is the magneto-motive force. The force is proportional to current and to the number of turns in the winding. This is often referred to as the amp-turns product. The drive which, supply the motor’s stator must act as a source of current and the applied voltage is only significant as a means of controlling the current. The input signals to the stepper motor’s drive consist of step pulses and a direction. Each pulse will be transform to one step of motor. The most commonly-used stepping mode in industrial applications is the half step and micro stepping mode in which the motor performs more steps per revolution [3]. The stepper motor drive elements are presented in figure 1.

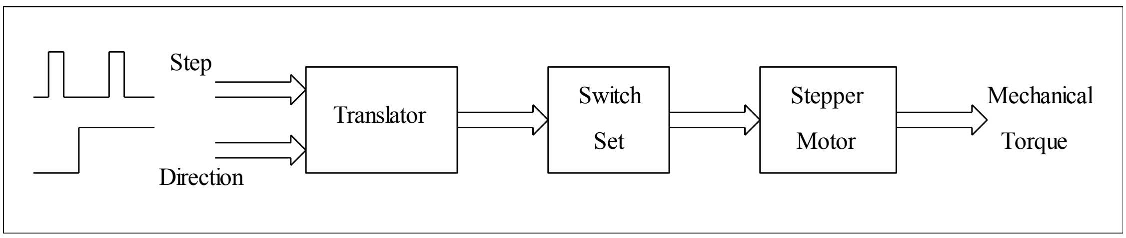


Figure 1. Stepper motor drive elements

The number of Step pulse will determine rotational shaft angle of stepper motor and frequency will determine the speed A translator of pulses can be realized as a ring counter, with the number of states equal to the number of motor phases. Input step pulse causes the counter to count either forward or backward, and therefore to command voltage phase to achieve hourly or counter-clockwise sense of movement of the rotor. When is necessary a control selection modus of pulses: the single sequence, double or mixed sequence the translator will become complicated, because it must include binary and gate signals for control mode selection. From translator the pulses are amplified in the switch set to have the level so the stepper motor to develop enough power or torque. Switch set is based on power transistors both unipolar and the bipolar connection. The winding of the stepper is a resistive - inductive load, with constant or periodic variable inductance depending of angle of rotation. The movement of the rotor generates an electromotive voltage in opposite of a principal voltage. Windings as inductive loads are switched on and off during each control pulse applied. It is necessary to resolve two problems: rapidly increasing supply current on rising edge of the pulse and protection of power transistors to inductive transient over voltages occurring in power failure in phase (decrease front) - called suppression. Forcing current through stepper's phase can be realized in many ways: Series resistance, resistors and capacitors, constant current electronic generator, two power supply voltage source and "chopper" method [5].

As is shown in figure 2, for a motor which have all the ends of coils external disposal, so called 8 wires stepper motor, there are possible unipolar connection, bipolar series connection, and bipolar parallel connection.

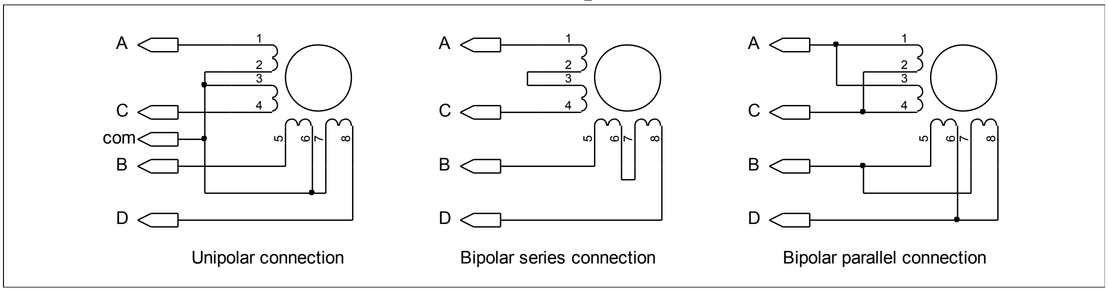


Figure 2. Connection of 8 wires Stepper Motor

2.1 Simulation of command of unipolar connection, full step.

Simulations were made in ORCAD - PSPICE for a stepper motor with 8 wires. For the first simulation were considered a stepper motor in unipolar connection and running in full step. The status of coils energizing are presented in Fig. 3, where A, B, C, D represents the coils and the numbers are sequences of shaft rotating. A driver based on wired logic using CMOS digital circuits and NMOS power transistors for double sequences were designed.

	A	B	C	D
1	1	1	0	0
2	0	1	1	0
3	0	0	1	1
4	1	0	0	1

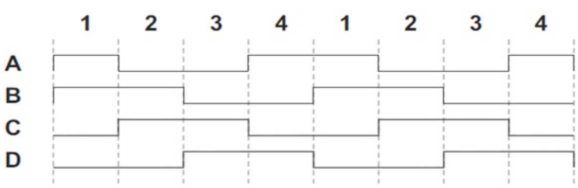


Figure 3. State of motor's coils and current evolution

In classical wired logic the necessary sequence is obtained using Flip Flops Register circuit as is shoved in figure 4.

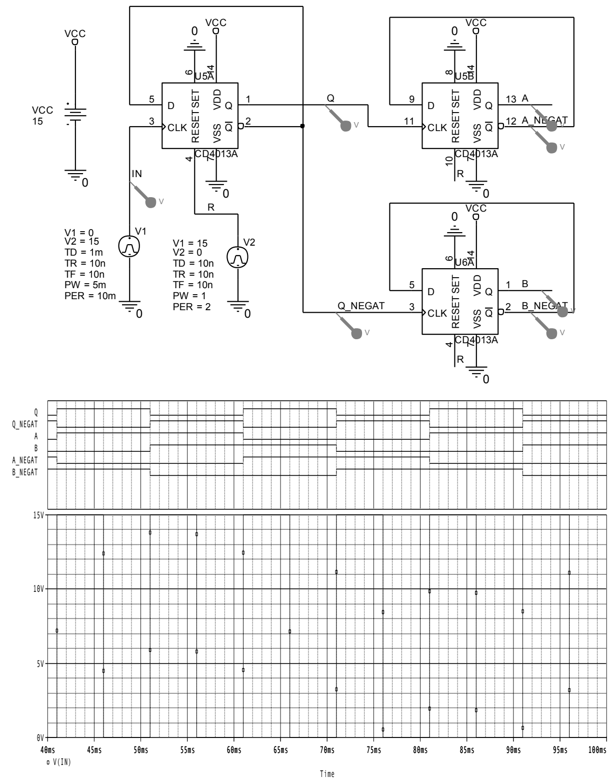


Figure 4. Schema used in simulation and sequence generating.

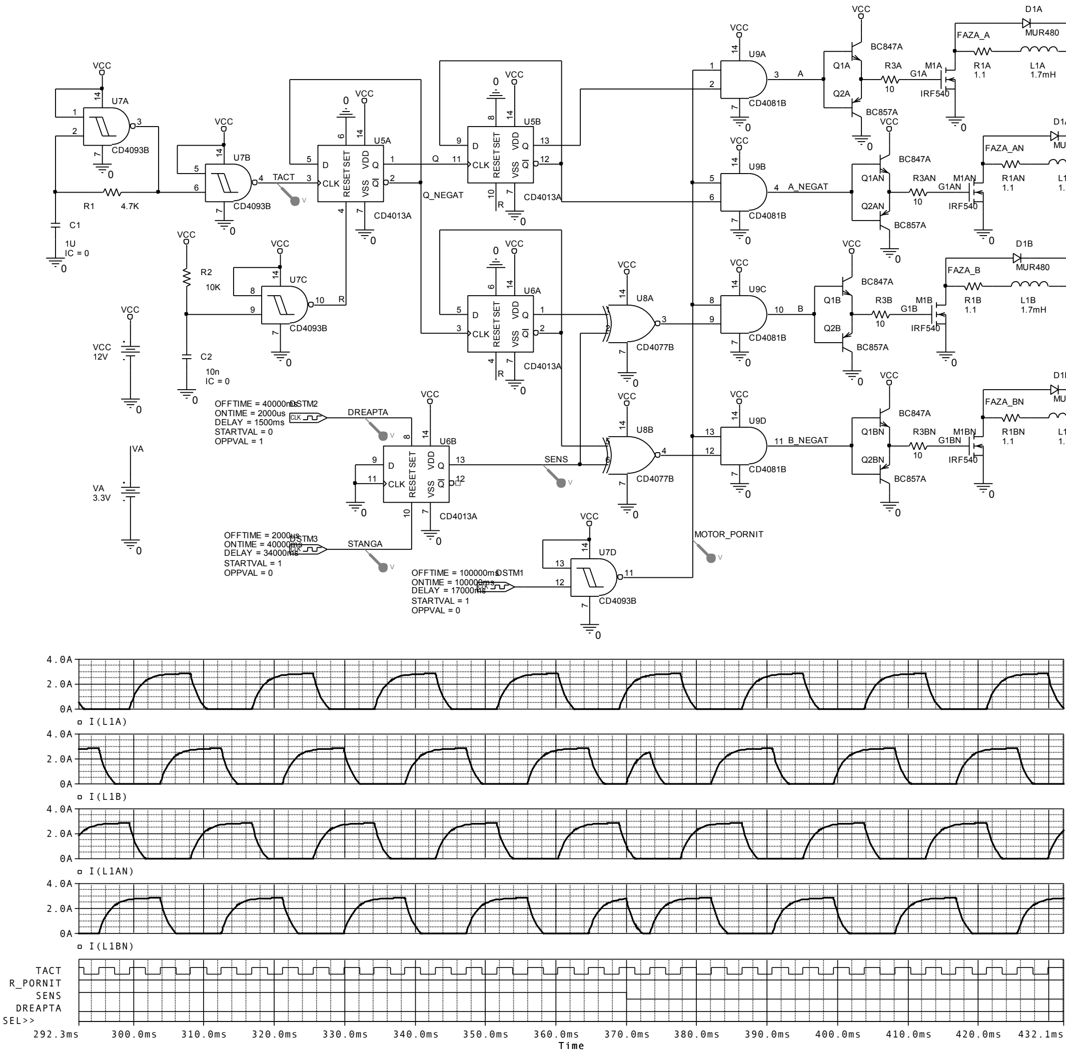


Figure 5. Enhanced schema used for unipolar stepper motor full step command and current evolution trough motor coils.

The schema, shoved in figure 5, was completed with step generator circuit named TACT, a reset circuit to begin on the imposed state for Latches, a circuit for stopping the current trough the motor coils, bipolar transistors drivers for charge and discharge rapidly input capacitance of NMOS power transistors, diodes for freewheeling current. In figure 5, you see the sequences of current trough the motor's coils, depending on the SENS signal. Electrical inertia, depending on the time constant L/R, discourage the use of stepper motor at high speed. In figure 6 are showed the sign of motor coils voltages and the evolution of current trough the bipolar motor connection.

	A	C	B	D
1	-	+	+	-
2	-	+	-	+
3	+	-	-	+
4	+	-	+	-

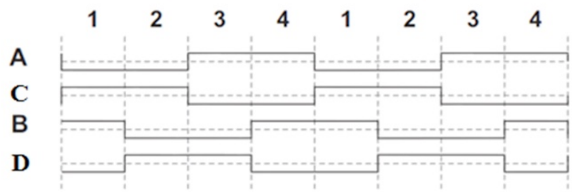


Figure 6. Motor's coils current evolution for bipolar full step

2.2 Simulation of command of bipolar connection, full step.

For motor used in experimental platform, the value of resistance and inductance, used in simulation schema, determines a time constant do the equation:

$$\tau = \frac{L}{R} = \frac{1.7mH}{1.1\Omega} \cong 1.55\ ms \qquad (1)$$

The current trough the motor coil comes by nominal value, after approximately four time constants:

$$4 \cdot \tau = 4 \cdot 1.55ms = 6.2\ ms \qquad (2)$$

The motor have 1.8 degree per step. A complete revolution runs for a time:

$$t = \frac{360^0}{1.8^0} \cdot 6.2ms = 200 \cdot 6.2ms = 1240\,ms \quad (3)$$

The maximum speed of motor is in this case:

$$n = \frac{60}{1.240} = 48\,RPM \quad (4)$$

The speed is too slow for most applications. For increase the speed the simplest way is to add in series an external resistor for reducing time constant. But this solution drastically decreases efficiency. The "chopper" method is used to decrease the rise time and the fall time too. The use of a singular power supply high voltage source is dangerous, the current trough the coil can reached to a big value. It is imperious necessary to limit the value of current at nominal value. In figure 7 is showed the principia schema to limit maximum current trough the motor coil, using logic and analogue circuits.

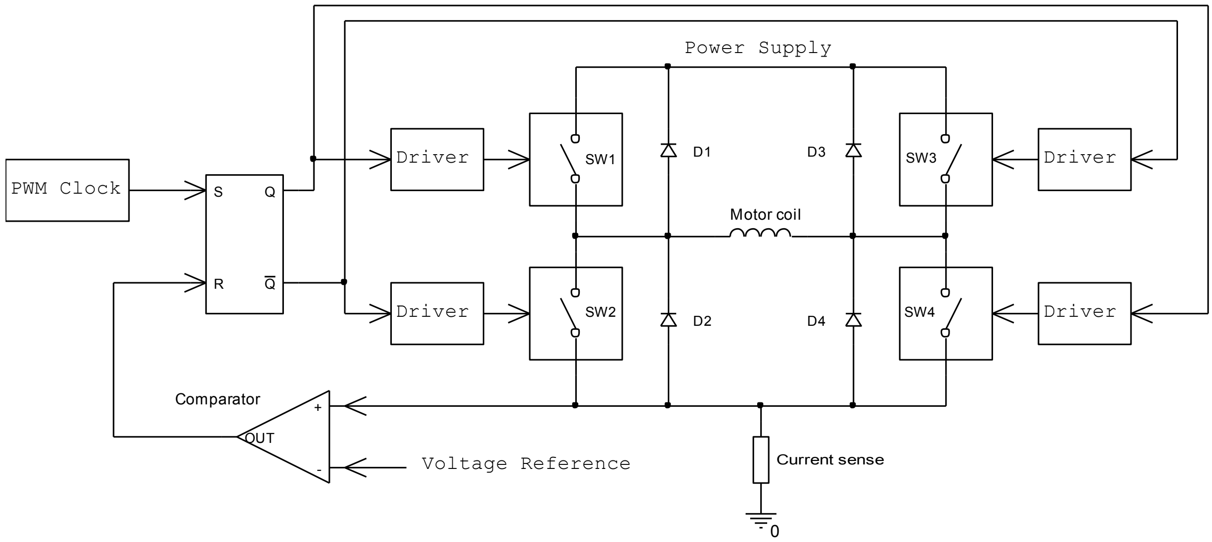
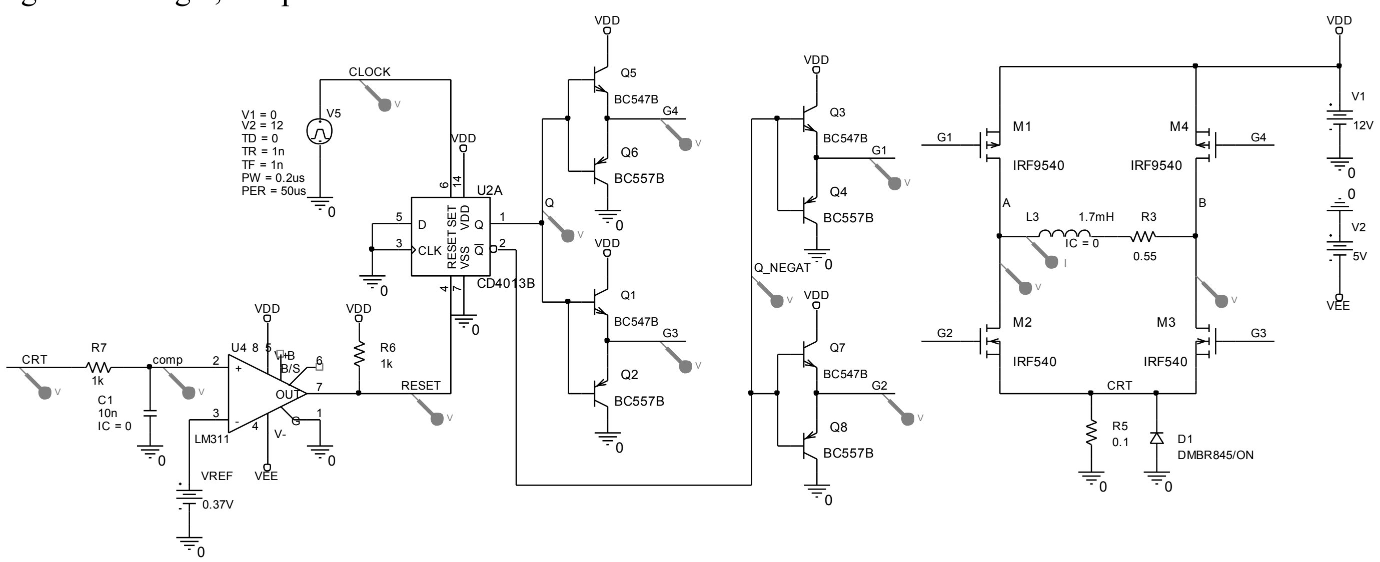


Figure 7. The principle of current limiting to the motor coil in bipolar connection

The current sense resistor gives a voltage proportional with current trough the motor coil. This value is compared with reference voltage. When current exceeds a maximum imposed value the output of comparator resets the Latch, the output Q begins zero logic, the pulse is finished and switches SW1, SW4 is turned "OFF" and SW2, SW3 is turned "ON", current trough the motor coil begins decrease. The detailed schema for one coil is presented in figure 8, and signal for enhanced schema signals.



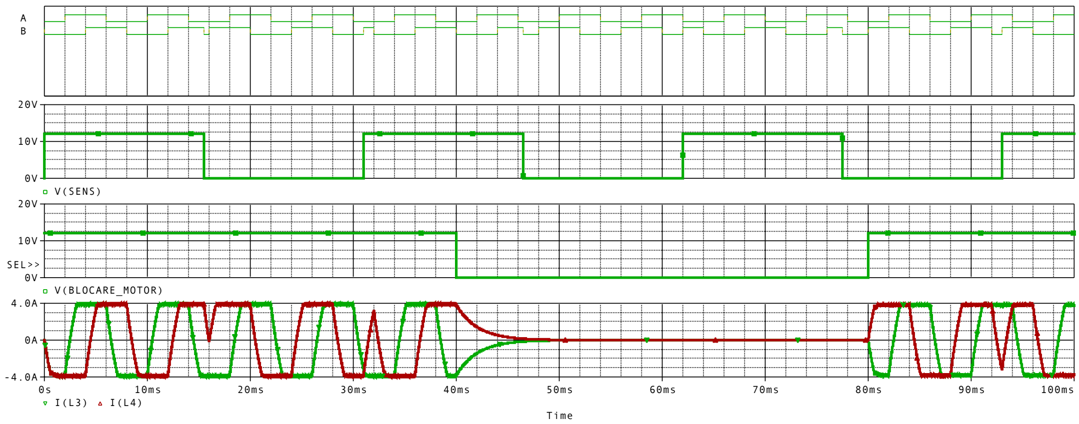


Figure 8. Schema used for current limiting bipolar stepper motor full step command and current evolution trough motor coils.

3. USING THE MICROCONTROLLERS FOR COMMAND AND CONTROL OF STEPPER MOTOR

A microcontroller offers much more flexibility and reduces the space used for printed circuit board [4].

The principle of current control using a microcontroller with analogue comparator inside is presented in figure 9

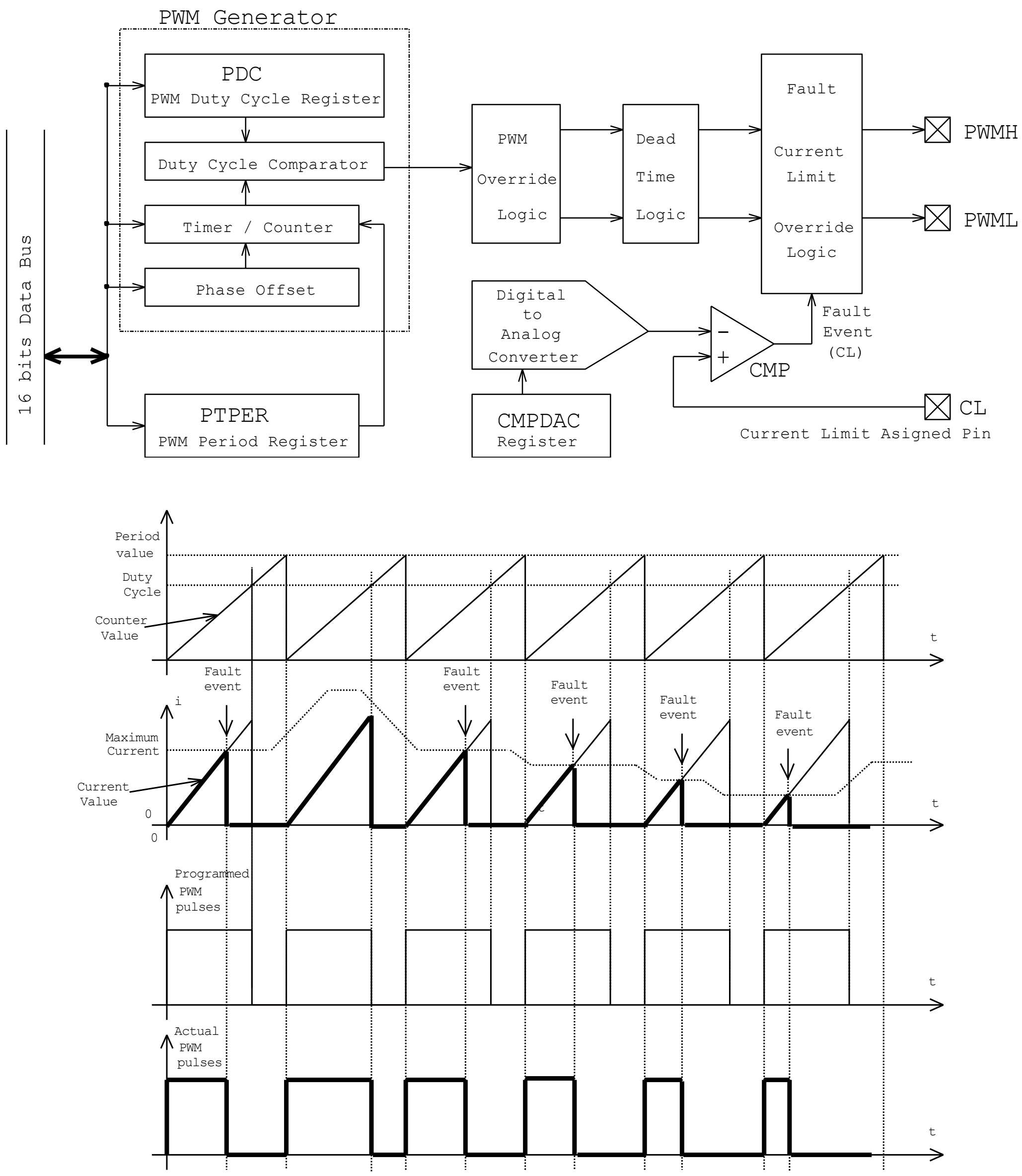


Figure 9. Principle of current control using a digital signal controller

The value of reference voltage is written in CMPDAC Register and this is obtained by Digital to Analogue Converter. A voltage proportional with the current is applied on CL pin and this is compared with reference value. The reference voltage is easy to change in software. The outputs PWMH and PWML command the driver and finally the power MOS transistor in the H Bridge [4].

4. EXPERIMENTAL SET

Experimental set is based on mechanical system like it used in industrial robots, machines tools and electrical discharge machines. It uses a ball shaft with step equal to 5 mm. The stepper motor can provide 1.8^o per full step. The transmission system with teethed belt have 1:1 ratio. This means that at a single step the table of mechanical system will execute a displacement of 40 microns. The coils of the stepper are supplied by a driver through power source. For program and control is used a prototype PCB with microcontroller dsPIC30F2020. The experimental current and voltage waves are visualised on the screen of Tektronix TDS3034B Oscilloscope. We were used a 50 amperes current probe TCP305 in conjunction with TCPA300 amplifier for motor coils current measurements.

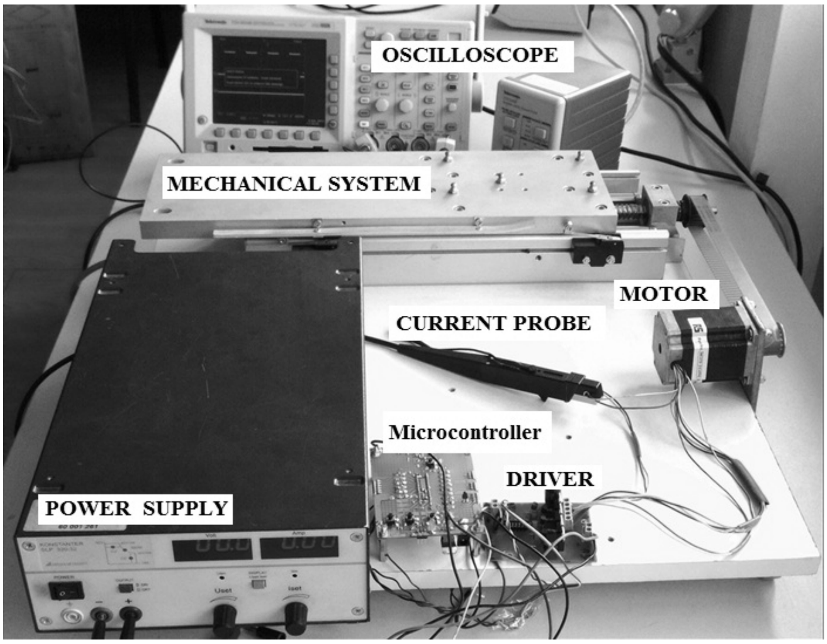


Figure 10. Experimental set

In figure 11 is presented the diagram of program:

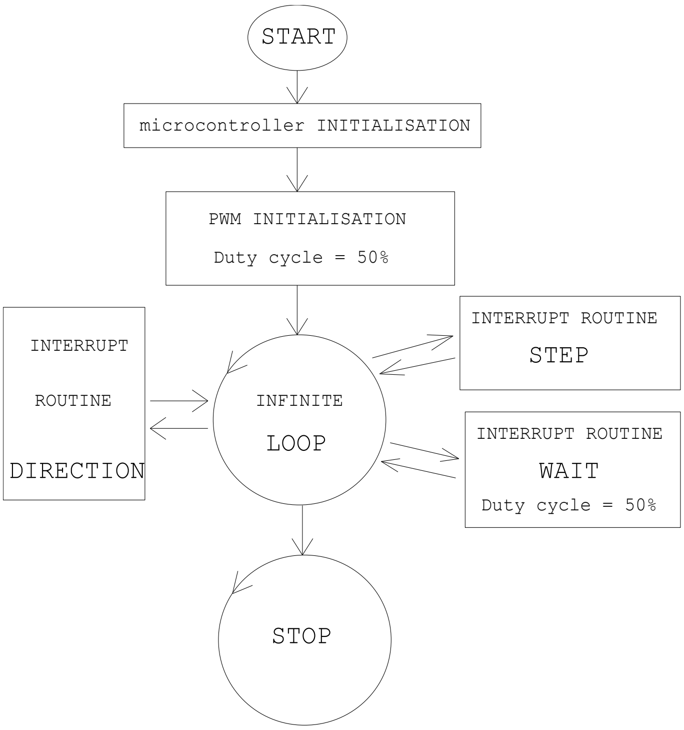


Figure 11. Program Flow Chart

The microcontroller has a very good interrupts system, and the program for stepping, half stepping or micro stepping is very simple. In this example the program run inside the infinite loop. An interrupt request goes out the loop for a short time.

5. REFERENCES

1. L. Bogdan, PLC as a driver for stepper motor control, *Annals of the Oradea University, Fascicle of Management and Technological Engineering*, Volume X (XX), ISSN1583-0691, p.3.9, NR1, (2011).
2. D. Nanu, *Tratat de tehnologii neconvenționale vol. II Prelucrarea prin eroziune electrică*, Ed. Universității "Lucian Blaga" din Sibiu, ISBN 973-695-071-9, (2004).
3. http://www.anaheimautomation.com/intro.htm.
4. http://www.microchip.com.
5. P.P. Acarnley, *Stepping motors: a guide to modern theory and practice*, 4-th Edition, The Institution of Engineering and Technology, ISBN 0-85296-417-X, (2002).