OPEN-LOOP CONTROL OF A BIPOLAR STEPPER MOTORS USING THE SPECIALIZED INTEGRATED CIRCUITS

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Abstract: The paper describes the open-loop control of a stepper motors. Bipolar stepper motors can be driven with an L297, an L298N bridge driver and very few external components. With an L298N this configuration drives motors with winding currents up to 2.5A. If very high powers are required an equivalent circuit made with discrete transistors replaces the bridge driver. Together these two chips form a complete microprocessor-to-stepper motor interface. The command signals for the controller L297 are generated through an IBM-PC486 interface. It was developed an open-loop command program written in BorlandC programming language.

Keywords: Stepper Motor, Stepper Motor Controller, H-Bridge Driver, PWM Chopper, Open-Loop Control.

1. INTRODUCTION

The progress of incremental motion control systems has been enforced by the multiplicity of their utilization: in numerically controlled machine-tool drives, peripheral computer equipments, telecommunications through laser and satellites, nuclear techniques, aeronautical and military equipments, industrial robots (Acarnley, 1992; Kuo, *et al.*, 1981).

The positioning systems are typical application of the stepper motor (SM) (Kenjo and Sugawara, 1994). The command boards for the complex positioning systems with SM generally involve complex functions and circuits. Researches concerning their synthesis in specialized integrated circuits have existed for a long time. Recent specialized circuits sets for stepper motors control allow achieving high performance systems in a very small volume. The main features of these circuits are (Kuo, *et al.*, 1981; Băluță, 1998):

- unipolar and bipolar command;
- initialization and direction reversal;
- the generation of usual command sequences for two or four phase SM (normal drive, wave drive and half step drive);
- on-chip PWM choppers for the switch-mode control of the current in the motor's windings;
- easy interfacing with microprocessor based systems, because of the reduced number of logical inputs.

Based on this, the author presents in this paper the bipolar command of a two-phase stepper motor using the specialized integrated circuits L297 (controller) and L298N (driver) produced by SGS-THOMSON.

2. THE L297 STEPPER MOTOR CONTROLLER

The L297 specialized integrated circuit generates four phases drive signals for two phases bipolar and four phase unipolar SM in microcomputer-controlled applications. The motor can be driven in half step, normal and wave drive modes and on-chip PWM chopper circuits permit switch-mode control of the current in the windings. The block diagram of the L297 stepper motor controller is shown in Fig.1.

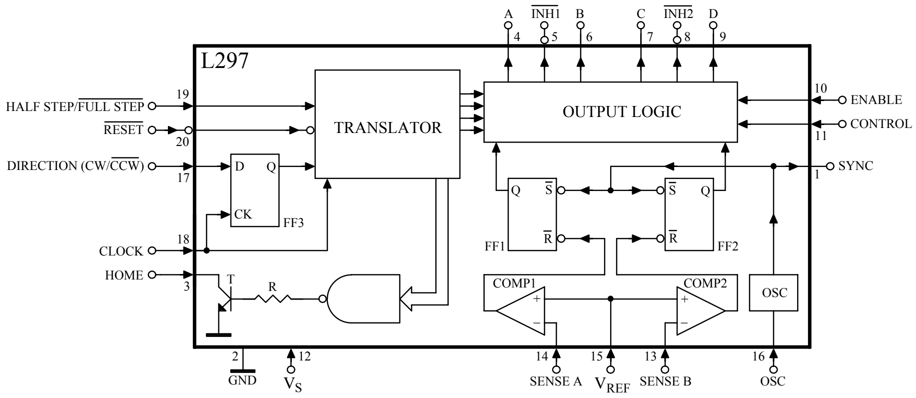

Fig.1. Block diagram of the L297 stepper motor controller.

The principal functions are a translator, which generates the motor phase sequences, and a dual PWM chopper circuit, which regulates the current in the motor windings (SGS-Thomson, 1988). The translator generates three different sequences, selected by the $\mathrm{HALF}/\overline{\mathrm{FULL}}$ input. These are normal (two phases energized), wave drive (one phase energized) and half step (alternately one phase energized / two phases energized). Two inhibit signals, $\overline{\mathrm{INH1}}$ and $\overline{\mathrm{INH2}}$, are also generated by the L297 in half step and wave drive modes. These signals, which connect directly to the driver's enable inputs, are intended to speed current decay when a winding is de-energized. When the L297 is used to drive a unipolar SM the chopper acts on these lines.

An input called CONTROL determines whether the chopper will act on the phase lines A, B, C, D or the inhibit lines $\overline{\mathrm{INH1}}$, $\overline{\mathrm{INH2}}$. When the phase lines are chopped the non-active phase line of each pair (AC or BD) is activated (Phillips, 1981).

A common on-chip oscillator drives the dual chopper. An external R_TC_T network (R_T to V_S and C_T to ground) connected to OSC terminal determines the chopper oscillator frequency:

$$(1)\ f_{OSC}=1/0.69 \cdot R_TC_T,$$

R_T must be more than 10KΩ. It supplies pulses at the chopper rate that set the two flip-flops FF_1 and FF_2. When the current in a winding reaches the programmed peak value the voltage across the sense resistor equals V_{REF} and the corresponding comparator resets its flip-flop, interrupting the drive current until the next oscillator pulse arrives. The peak current for both winding is programmed by a voltage divider on the V_{REF} input.

Other signals are:

-the clockwise/anticlockwise direction control input $\mathrm{CW}/\overline{\mathrm{CCW}}$;

-the asynchronous reset input $\overline{\mathrm{RESET}}$ (an active low pulse on this input restores the translator to the home position ABCD=0101);

-the open collector output HOME that indicates the L297 is in its initial state (ABCD= =0101);

-the chip enable input ENABLE (a low level on this input brings $\overline{\mathrm{INH1}}$, $\overline{\mathrm{INH2}}$, A, B, C and D low, de-energized the motor windings).

3. THE L298N DUAL H-BRIDGE DRIVER

The L298N integrated circuit is a high voltage (up to 46V), high current (total DC current up to 4A) dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepper motors. The block diagram of the L298N dual full-bridge driver is shown in Fig.2. Two inhibit inputs, ENABLE A and ENABLE B, are provided to disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected

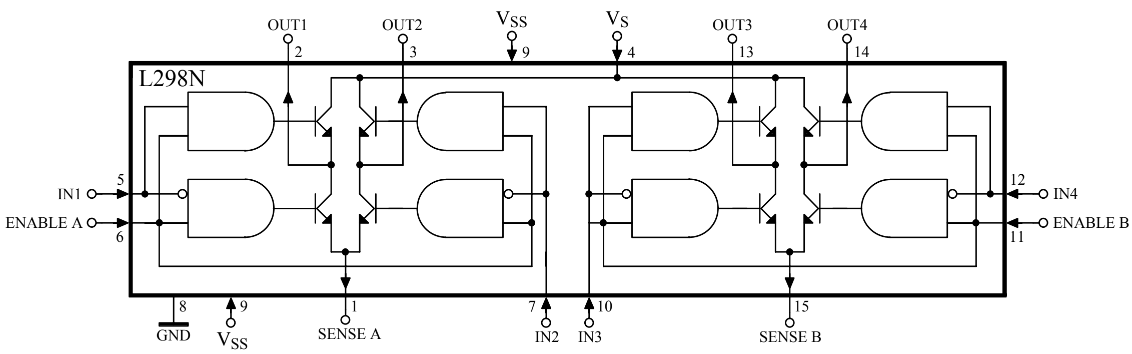

Fig.2. Block diagram of the L298N dual H-bridge driver.

together and the corresponding external terminal, SENSE A and SENSE B, can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage (SGS-Thomson, 1988).

Some form of load current control is essential to obtain good speed and torque characteristics. There are several ways in which this can be done-switching the supply between two voltages, pulse rate modulation chopping or pulse width modulation chopping (Unitrode, 1994).

The L297 provides load current control in the form of two PWM choppers, one for each phase of a bipolar or one for each pair of windings for a unipolar motor. Each chopper consists of a comparator COMP, a flip-flop FF and external sensing resistor R_S (Fig.3).

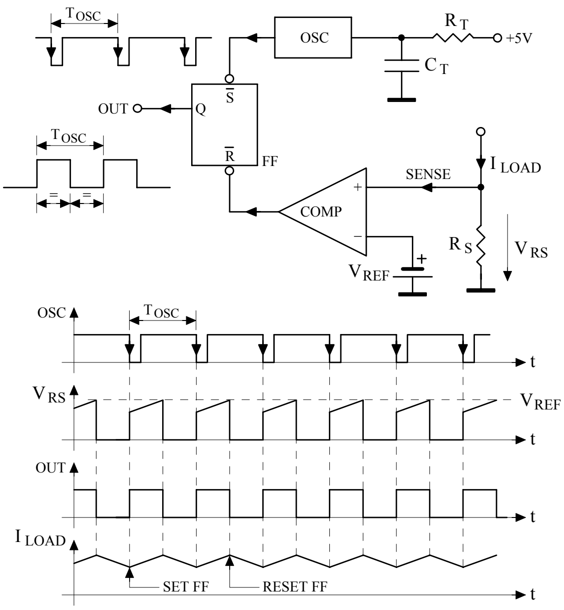

Fig.3. Load current control.

The chopper can act on either the phase lines (A, B, C, D) or on the inhibit lines $\overline{INH1}$ and $\overline{INH2}$. An input named CONTROL decides which. Inhibit chopping is used for unipolar motors but you can choose between phase chopping and inhibit chopping for bipolar motors.

The phase chopping is shown in Fig.4. The energy stored in the winding is dissipated by current recirculating through T_1 and D_3. Current decay through this path is rather slow because the voltage on the winding is low ($V_{CEsat\,T\,1} + V_{D3}$).

The alternative is to tie the CONTROL input to ground so that the chopper acts on $\overline{INH1}$ and $\overline{INH2}$. Looking at the same example, A is high and C low. The transistors T_1 and T_4 are therefore conducting and current flows through T_1, the winding, T_4 and R_S (Fig.5). In this case the voltage across R_S reaches V_{REF} the chopper flip-flop is reset and $\overline{INH1}$ activated. The $\overline{INH1}$ signal, remember, turns off all four transistors therefore the current recirculates from

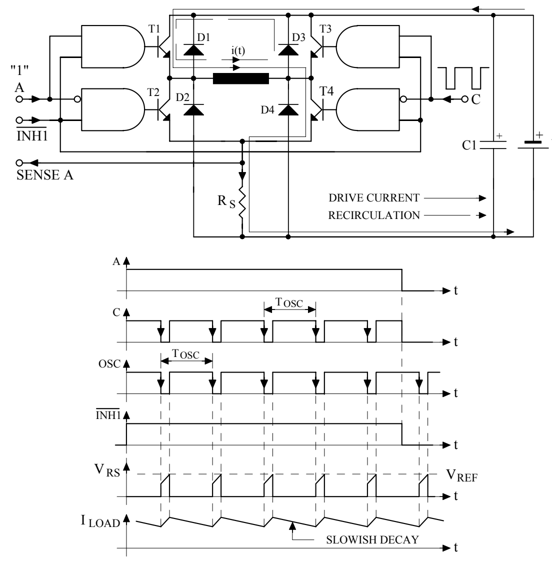

Fig.4. Phase chopping.

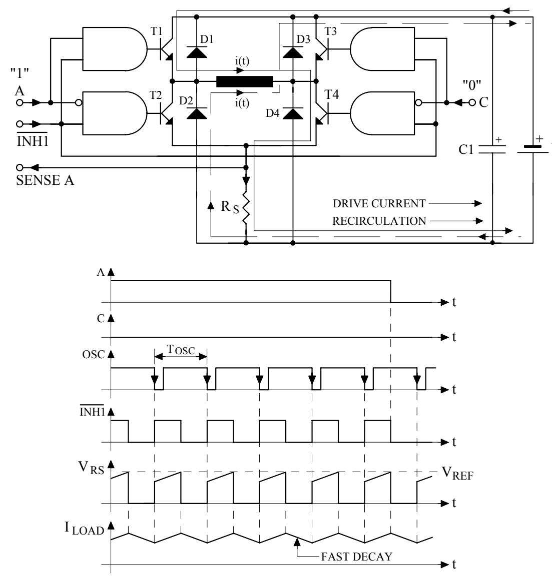

Fig. 5. Inhibit chopping.

ground, through D_2 the winding and D_3 to V_S. Discharged across the supply, which can be up to 46V, the current decays very rapidly.

4. SYSTEM'S DESCRIPTION

The block diagram of the achieved system is shown in Fig.6. The main component of the command block is the integrated specialized circuit L297. The L297 can be used with monolithic bridge drives such as the L298N or L293E or with quad Darlington array or discrete power devices (Băluță, 2004b).

The achieved system has the possibility of the local control, implemented by the LOCAL COMMAND block. The main component of the ANALOGUE MEASUREMENT block is the current transducer LEM Modules (Băluță, *et al.*, 1996). The electrical schematic of the achieved system is shown in Fig.7.

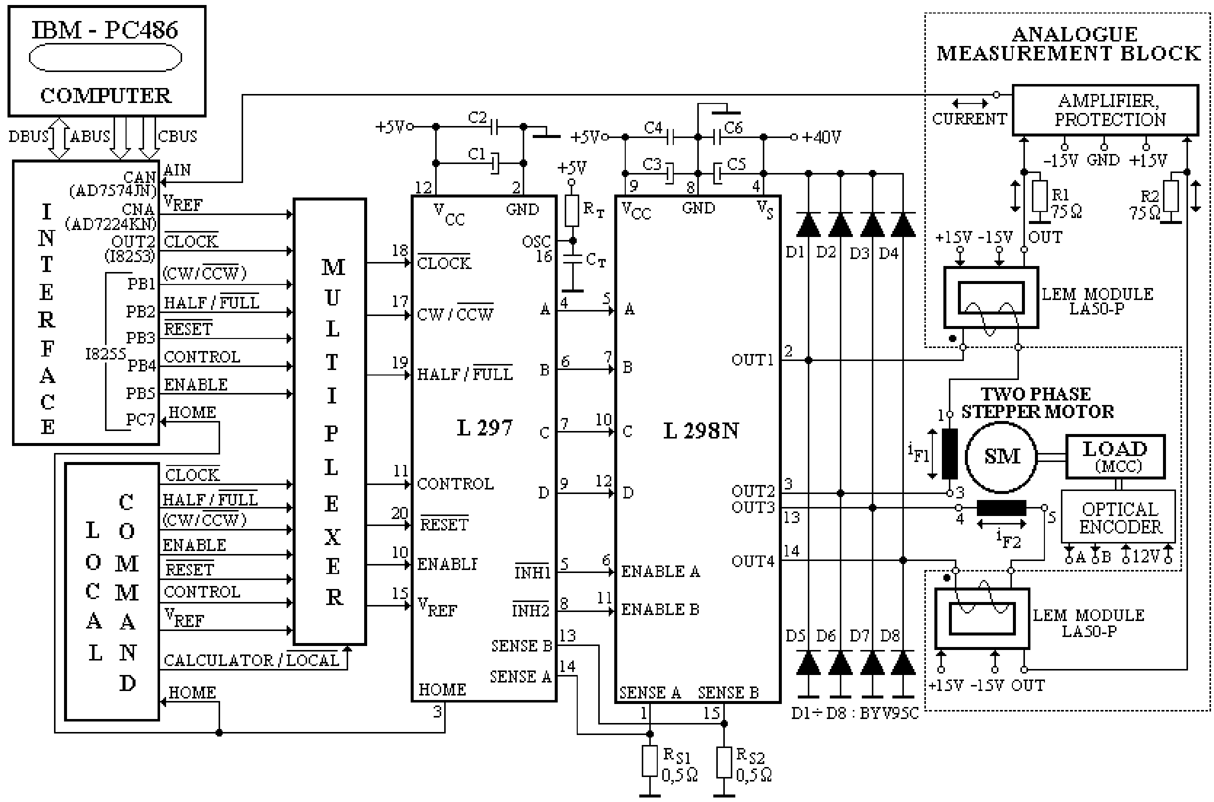

Fig.6. Block diagram of the control system.

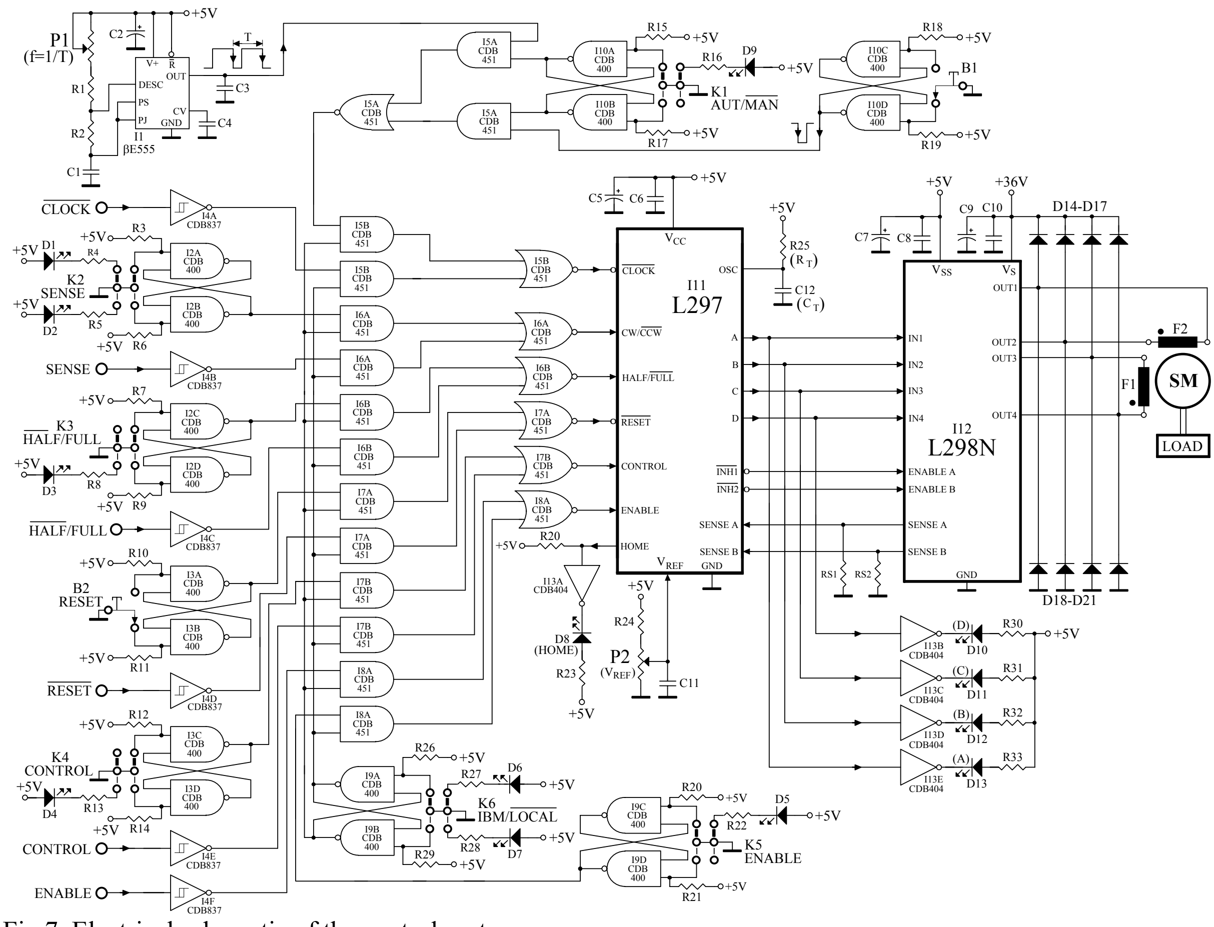

Fig.7. Electrical schematic of the control system.

The command signals for the controller L297 are generated through an IBM-PC486 interface (Băluță, 2004a). It was achieved on a so-named "prototyping board" (for which a connector equips the computer's mother board) and contains the necessary elements for both the open-loop control and the closed-loop one. The author has developed an open-loop command program (written in BorlandC programming language) capable to use the IBM PC features in order to achieve a friendly operator to motor interface. The flowchart corresponding to the command program is shown in Fig. 8 (Băluță, 2003).

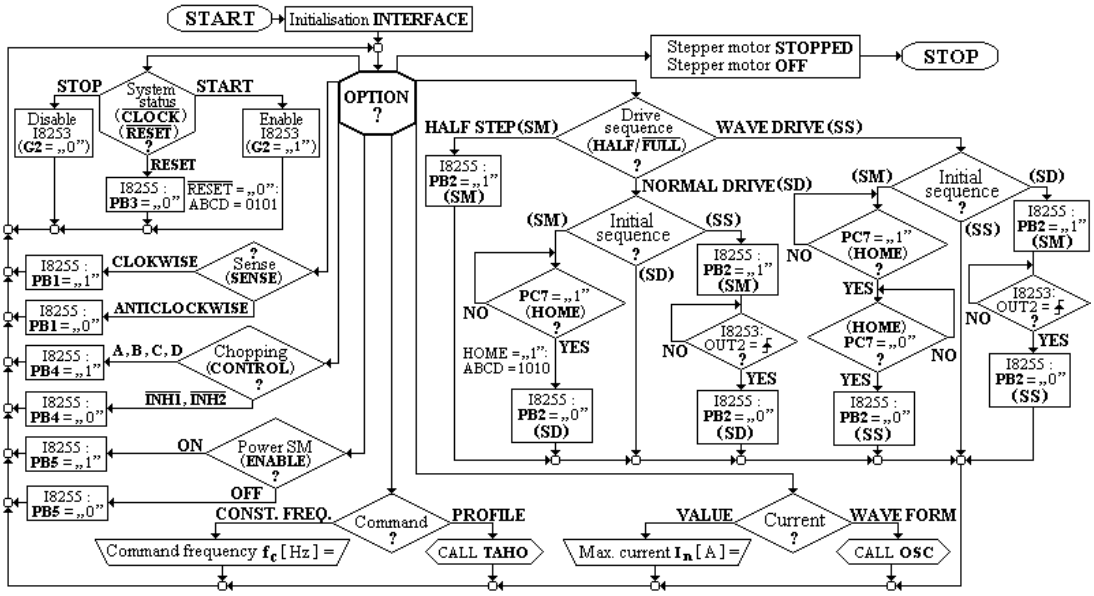

Fig.8. The flowchart of the main program.

The SM control can be driven with constant frequency (CONST. FREQ.) or with (linear or exponential) prescribed speed profile (PROFILE). The BorlandC program establishes at the beginning, in a conversational manner, the operational parameters (frequency, number of steps, profile characteristics), the drive sense (clockwise or anticlockwise), the drive sequence (normal drive, wave drive and half step), the chopping mode (the phase lines or the inhibit lines) and maximum phase current. The main menu of the command program is shown in Fig.9 (Baluță, 2003).

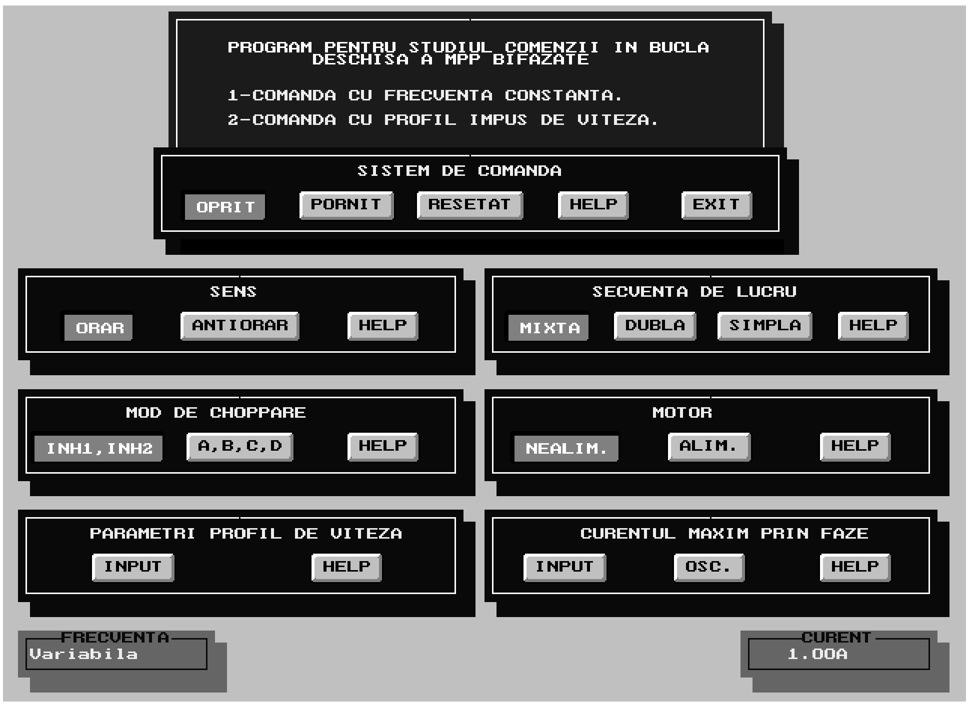

Fig.9. The main menu of the command program.

Due to the graphical interface, even a less prepared user can supervise the main parameters of the drive system, impose a linear or exponential speed profile in order to minimize the positioning time or analyse

the phase current curves. The algorithm that generates the command pulses for the linear profile of the prescribed velocity is shown in Fig.10. The algorithm for the exponential profile of the prescribed velocity was developed in a similar manner (Băluță, 2003; Sinha, 1985).
The software is the operator level interface with the electrical drive system. It allows the operator to modify off-line or on-line the working parameters of the drive system by using the computer mouse device and manipulating windows and buttons on the screen. Although the graphical looking is closed with the Windows GUI, the program here presented has the advantage of running directly under DOS operating system, being able to be used on previous generations of IBM PC compatible computers, which cannot support the Windows system (Kernigham and Ritchie, 1988).

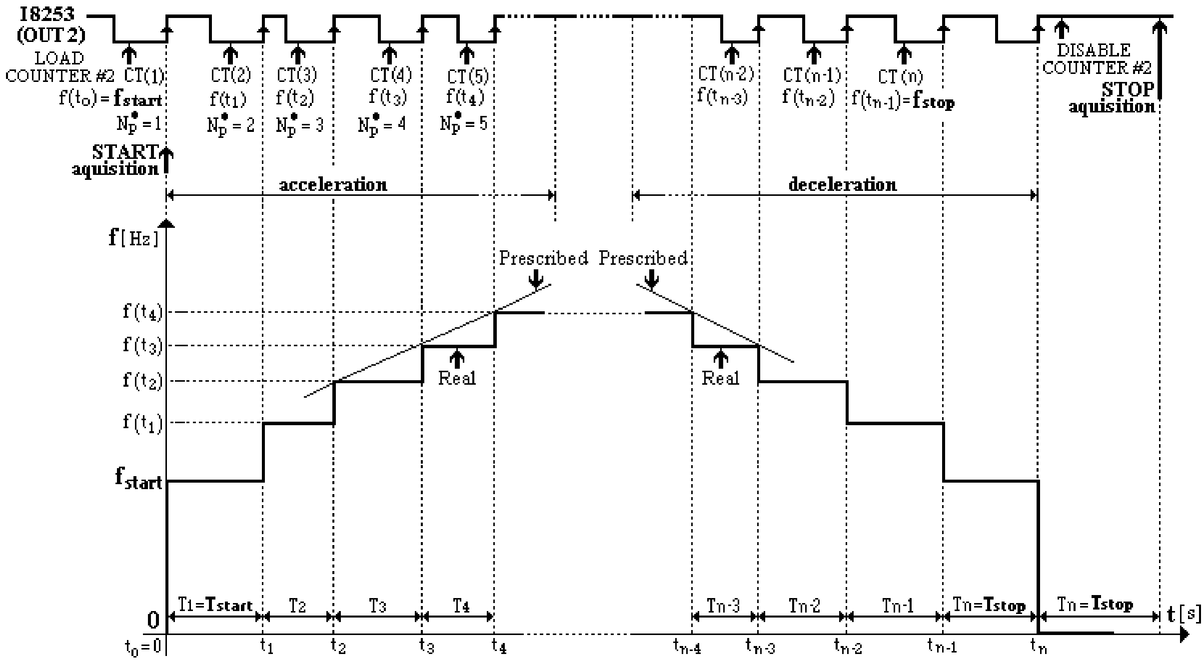

Fig.10. The algorithm that generates the command pulses for the linear speed profile.

5. EXPERIMENTAL RESULTS

The experimental researches were effectuated in the Electrical Drives Laboratory from the Electrical Engineering Faculty of Iași, where it was achieved an electrical drive system using two-phase bipolar SM (step angle θ_p=1.8°, nominal voltage supply U_n=5V, current per phase I_n=1A, resistance per phase R_f=5Ω, holding torque M_{max}=0.3N·m). The results obtained experimentally justify the flexibility of these systems in which the working parameters can be easily modified, allowing a fast adaptation of the drive system to load variations (Băluță, 2003; Băluță, 2004a). The experimental system used in laboratory is shown in Fig.11.
As experimental results, the phase currents of a two-phase bipolar stepper motor are shown in figures 12, 13 and 14. These currents were measured in the following operating modes of stepper motor: wave drive mode (Fig.12), half step mode (Fig.13) and normal drive mode (Fig.14). The command pulses, positive-edge actives, are also presented. In this case the CONTROL input is low, the choppers acting on the inhibit lines $\overline{INH1}$ and $\overline{INH2}$.

In Fig.15 is shown the phase currents for wave drive mode, in the case of a high level on CONTROL input which means the choppers acts on phase lines A, B, C, D. Looking at Fig.12 to Fig.14 comparative with Fig.15 we can see the difference between the two chopping modes. When the chopper acts on the phase lines, the current decay is slow because the voltage on the winding is low. When the chopper acts on the inhibit lines, the current decays very rapidly because discharged across the supply, which can be up to 46V (SGS-Thomson, 1988).
Some of the experimental results are presented:
-the linear profile of the prescribed velocity (Fig.16);
-the exponential profile of the prescribed velocity (Fig.17);
-the position and the angular speed for command with constant frequency (20Hz, Fig.18) and with exponential profile of the prescribed velocity (1181 steps, Fig.19);
-a complete positioning cycle (1181 steps, Fig.20).
The specialized circuits L297-L298N and a minimum of external compo nents form a complete control and drive unit for-TTL or microprocessor-controlled stepper motor systems for currents up to 2,5A.

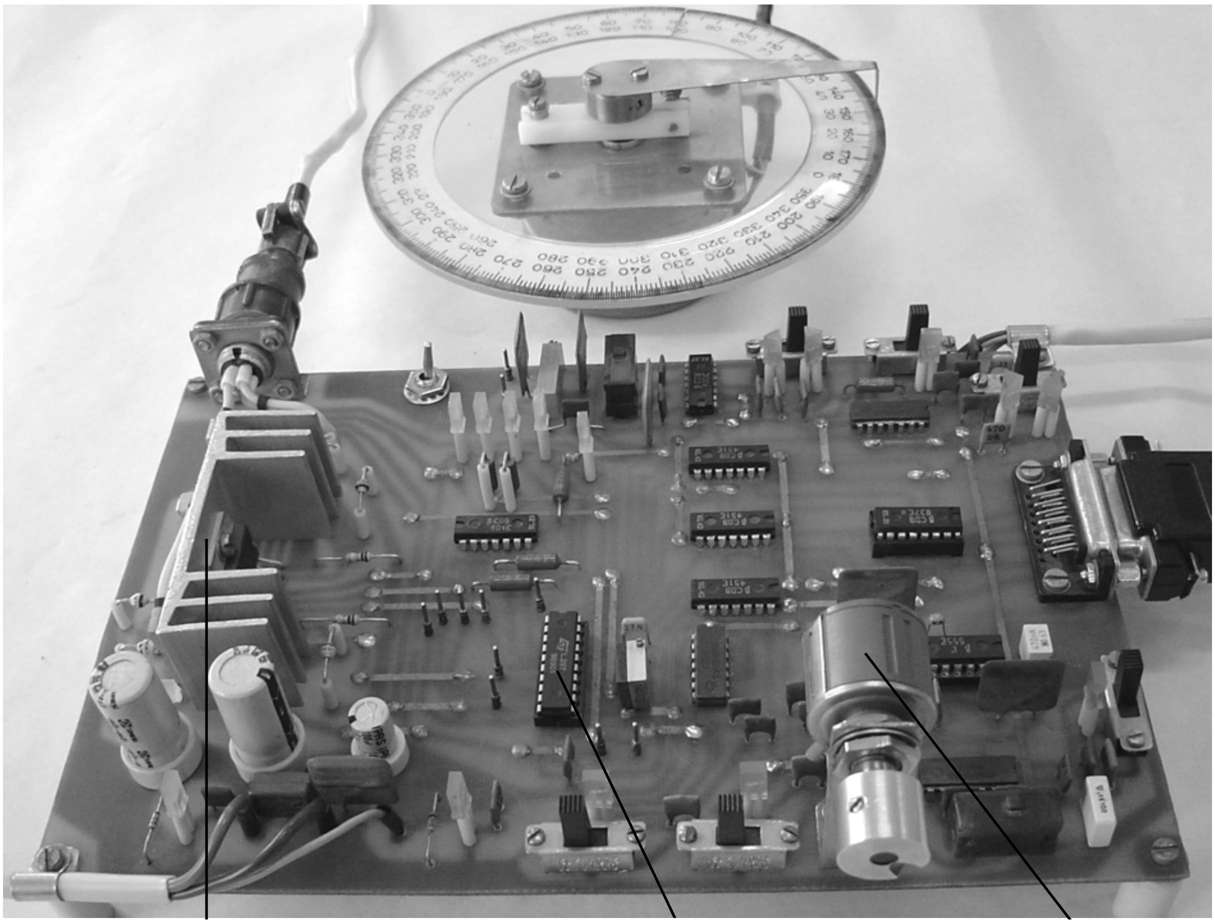

Fig.11. The experimental system used in laboratory.

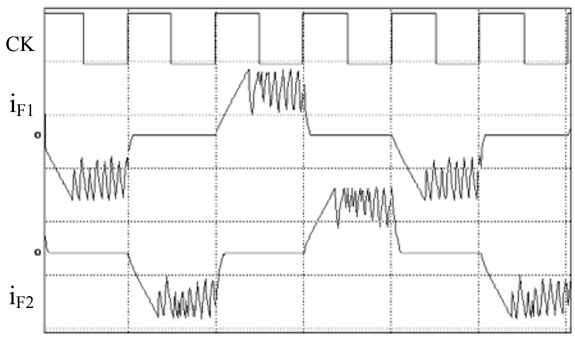

Fig.12. The phase currents in wave drive mode, the inhibit chopping (0.4A/div., 5ms/div.).

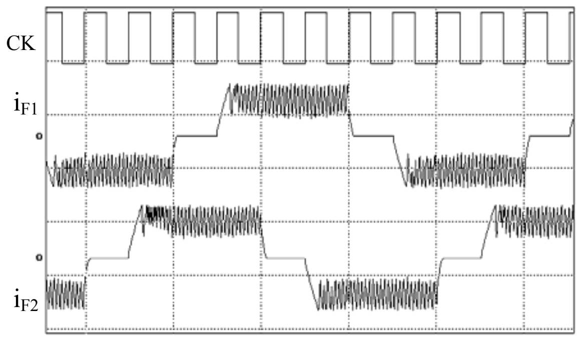

Fig.13. The phase currents in half step mode, the inhibit chopping (0.4A/div., 5ms/div.).

6. CONCLUSIONS

The modern solutions involve new power semiconductor devices with high performances, dedicated command circuits with multiple specific functions and new control techniques.

The precision positioning system presented in this paper has folowing advantages:

-very few components are required (so assembly costs are low, reliability high and little space required);

-the choice of a two-chip approach gives a high degree of flexibility;

-software development is simplified and the burden on the micro is reduced.

Applications of the L297 (controller)-L298N (driver) can be found almost everywhere: printers (carriage position, daisy position, paper feed, ribbon feed), typewriters, plotters, numerically controlled machines, robots, floppy disk drives, photocopiers, telex machines, photographic equipment, electric valves and so on.

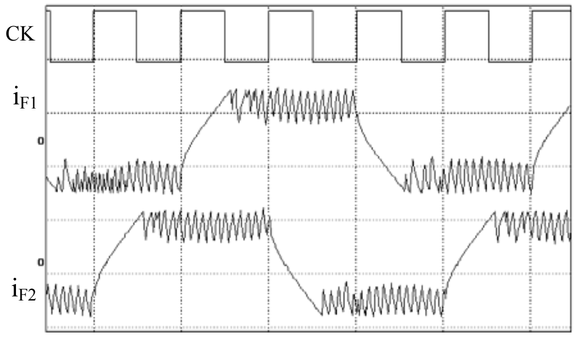

Fig.14. The phase currents in normal drive mode, the inhibit chopping (0.4A/div., 5ms/div.).

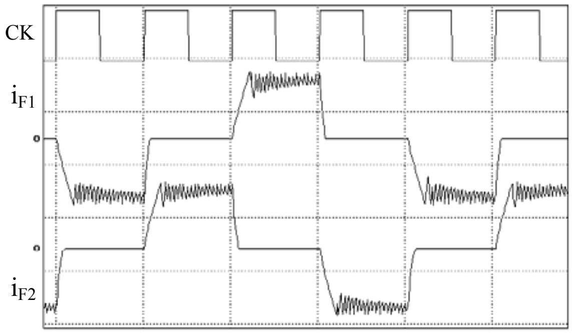

Fig.15. The phase currents in wave drive mode, the phase chopping (0.4A/div., 5ms/div.).

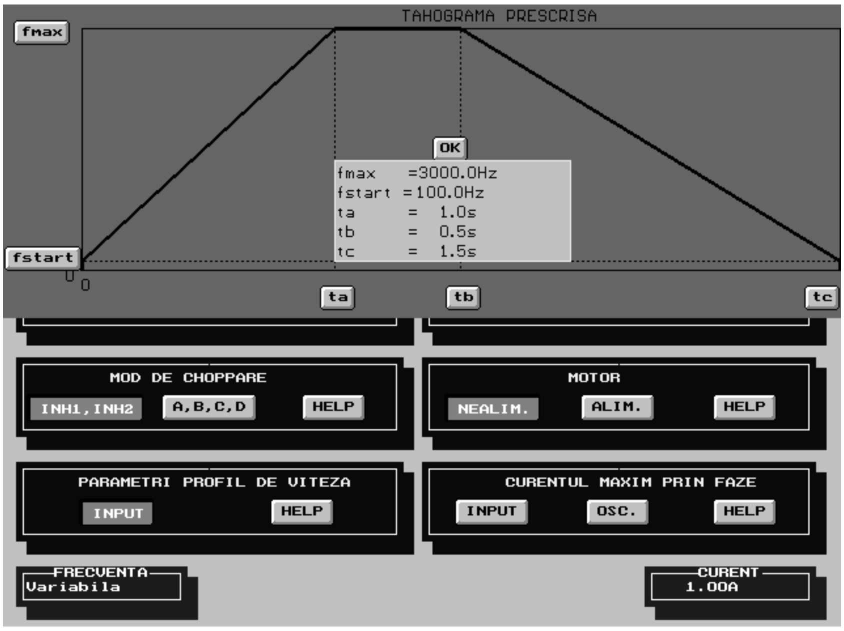

Fig.16. Linear profile of the prescribed velocity.

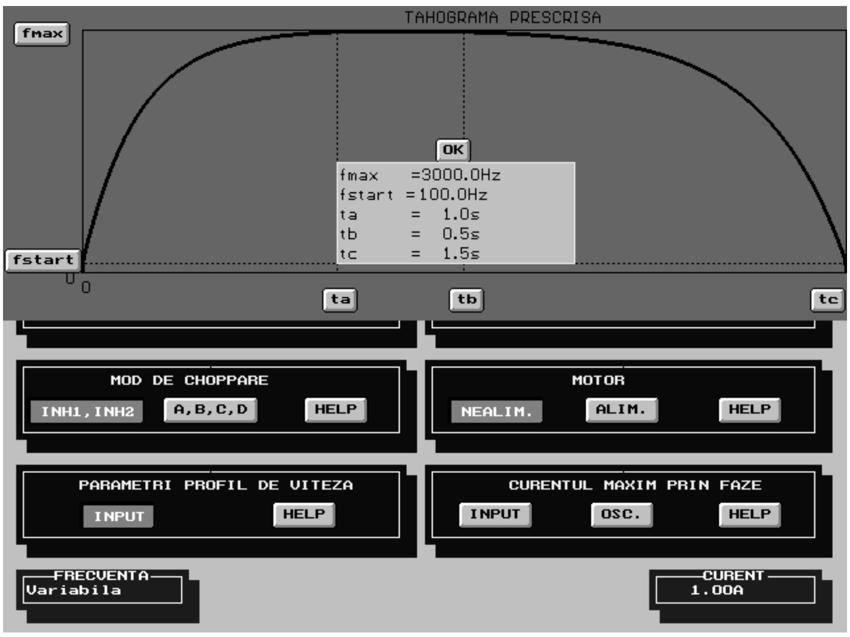

Fig. 17. Exponential profile of the prescribed velocity.

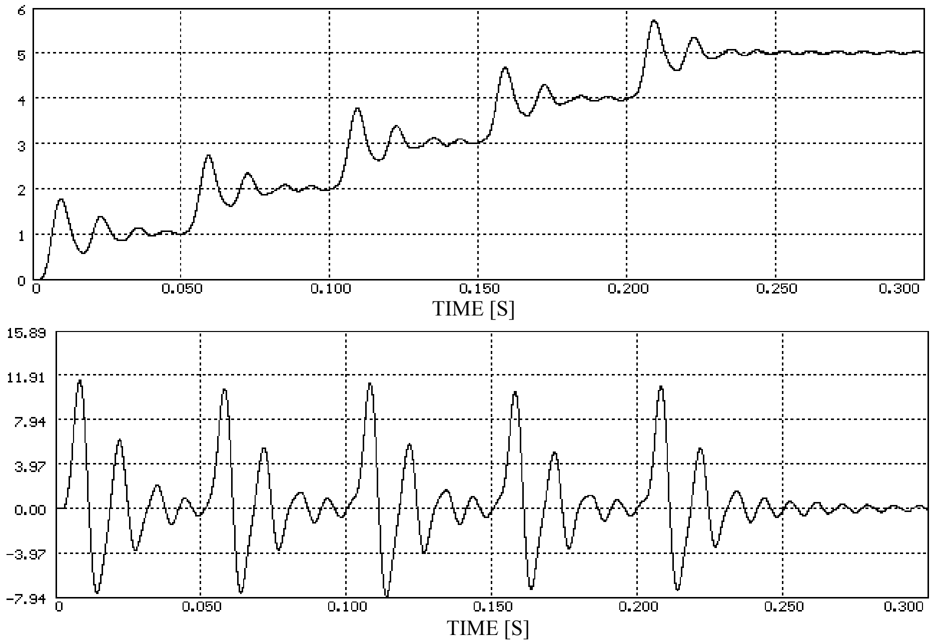

Fig.18. The position and the angular speed for command with constant frequency.

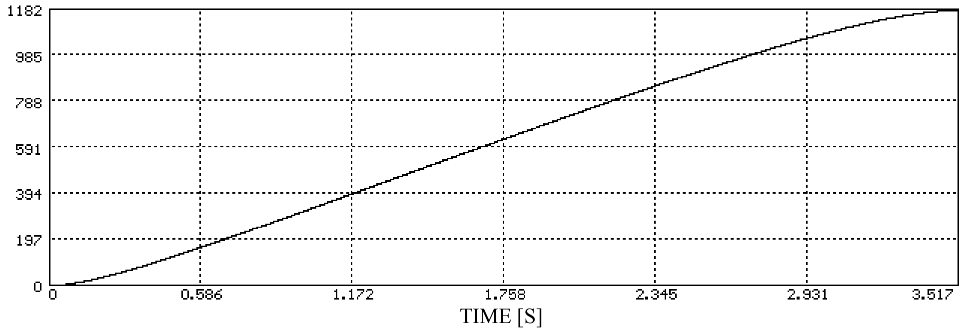

Fig.19. The position for command with exponential profile.

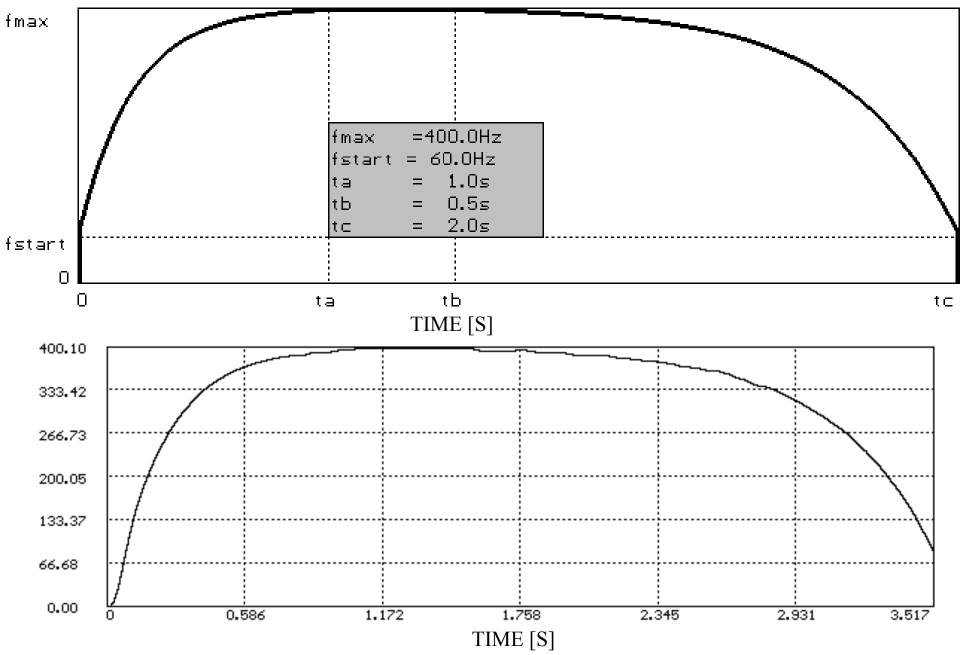

Fig.20. Prescribed speed profile and real speed profile.

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