Rudolf JALOVECKY[1], Michal DUB[2]

University of Defence (1), University of Defence (2)

DC motor unipolar PWM control

***Abstract**. The paper deals with design and construction of unipolar PWM driver for DC motor motion control. The drive control element is ADuC812 microcontroller, which not only controls DC motor but also process information from several sensors. There are described used electric drive characteristics, principle of PWM control and particular block diagrams including comments and photographs of developed system.*

***Streszczenie.** W artykule zaprezentowano projekt i konstrukcję jednobiegunowego napędu silnika DC. Do tego celu wykorzystano mikrokontroler ADuC812 który dodatkowo przetwarza dane z czujników. (**Jednobiegunowy napęd silnika DC z wykorzystaniem metody PWM**)*

Keywords: DC motor, motion control, PWM driver, microcontroller ADuC812
Słowa kluczowe: silnik DC, PWM, mikrokontroler.

Introduction

The use of the PWM control of electric motor is considered to be one of the modern as well as ecological approaches to the motion control of the electrical drives. These new designed systems have been replacing out of date drives in last years.

The PWM speed controllers of separately excited DC motors work by changing the average voltage sent to the armature winding. The best solution how to change this average voltage is to use full-bridge circuit around armature winding [1][2][3].

A full bridge circuit contains four switchers usually performed by power MOSFETs or IGBTs and freewheeling diodes. Transistor's switching algorithm determines the frequency and width of pulse voltage sent to the armature winding. If the switching frequency is high enough, the motor identifies only the average effect, which is given by pulse voltage width. Turning on only one MOSFET on each side of the motor at any one time have to be assured to prevent short out source of supply voltage.

Bipolar and unipolar switching algorithms are given by switching power MOSFETs. It is unipolar switching algorithm (see Fig. 1) if only one polarity of armature winding voltage is used during PWM signal period. The use of positive and negative polarity of armature winding voltage during PWM signal period defines bipolar switching algorithm. Another algorithm classification is given by switching only one MOSFET or both MOSFETs in each side of PWM controller [1].

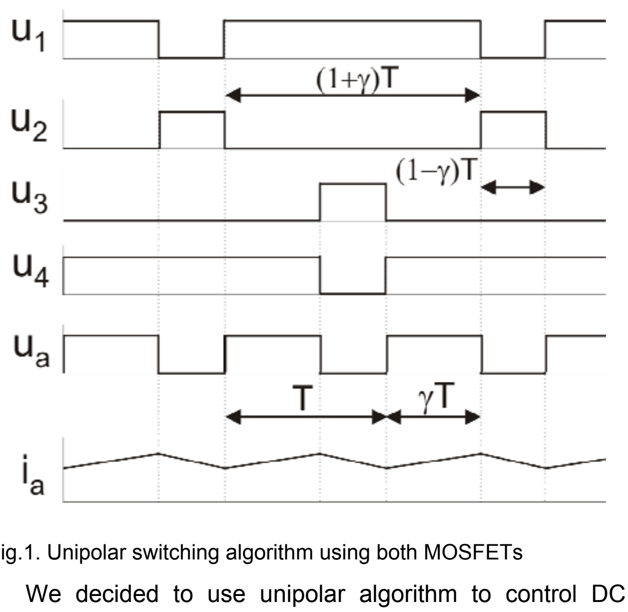

Fig.1. Unipolar switching algorithm using both MOSFETs

We decided to use unipolar algorithm to control DC drive in designed commercial door system. The whole commercial door system is represented by ten independently opened sliding doors and basic requirements for this particular application were strictly given. The basic function of the primary system is to open single sliding door based on the detection of a human body motion (or any other motion) in the area in front of the door and to close it after predefined time if no motion in the door area was detected. There is an advanced function of a primary system interlock being activated when dangerous situation occurs and the doors are opened in sequences with possible time control.

Another door control is possible via manual control when the detection system is intentionally switched off. The reliability of the system is enhanced by power supply backup. The 18 Volts DC power system with backup battery is fed from the 230 Volts AC power supply. The battery is able to open all doors in case of external power supply failure [4][5].

System design

PWM controlled DC drive can be designed in two basic ways. Fist way is the logic circuits based method. The second way is the microcontroller based solution we used. The primary system of the commercial door motion system is designed from several parts according to the Fig. 2.

Basic part is the ADuC812 microcontroller, which not only controls sliding door motion but also processes information from several sensors. The PWM driver is based on BTS780GP power module [6] and the DC motor armature is directly fed from the power MOSFETs of the PWM driver. Toothed belt converts the Valeo 0273 GML type DC motor rotation motion to the sliding door motion.

Motor rpm is measured by HEDR 542 encoder and the velocity feedback is connected to ADuC812 microcontroller where computing programme for the door motion velocity stabilization is running. The door position is indicated by signals from four GL-N12 series inductive proximity sensors that cause Interrupt ReQuest of the running program. The obstacle in the door area is detected by four MS-112 passive infrared motion sensor modules. Fire alarm system is not integral part of the commercial door motion system. Signal from fire sensor opens the doors one after another or in time sequences.

The initial conditions such as door motion velocity and PWM signal frequency of the full bridge power transistors are entered from user PC via USB interface. It is also possible to use USB interface to load the program into control processor and to get information from it during program compilation.

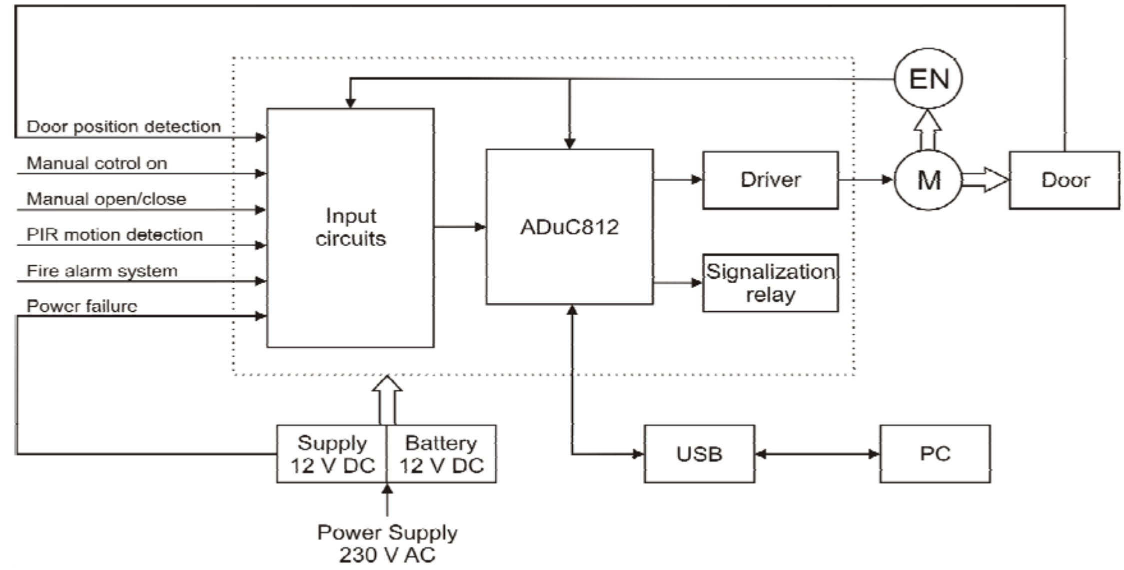

Fig. 2 PWM controller block diagram

PWM driver design in detail

Basic part is microcontroller ADuC812, which assures automatic control process. Although ADuC812 has three internal interval timers, PWM signals generation for power module was solved by three external programmable interval timers (PIT) 8254. Chosen solution is then more universal and in case of need independent on used microcontroller. Internal PITs are used for serial communication, rpm measurement and run of whole application. Microcontroller controls three external PITs through standard SPI interface.

First PIT works as frequency divider to gain PWM signal frequency (time period T in Fig. 1) from microcontroller oscillator frequency. PWM signal frequency can vary from 400 to 600 Hz. First PIT output signal duty cycle is 0.5. Other two PITs then generate PWM signals u_1 and u_4 for power module transistors T1 and T4 (pulse width $(1+\gamma)T$ in Fig. 1).

Complementary signals u_2 and u_3 for power module transistors T2 and T3 are derived in delay logic circuits. Special attention has to be focused on dead time control of the complementary PWM signals for power module transistors T1-T2 and T3-T4 due to possible crossover currents. All PWM signals are delayed in delay logic circuits and then transferred to power module BTS780GP.

The BTS780GP contains one double high-side switch and two low-side switches in one package. Typical switching times are 130 μs for switch-off and 260 μs for switch-off operation, maximal values are 300 μs for switch-off and 450 μs for switch-off operation.

Therefore 130 μs dead time control of the complementary PWM signals was chosen. Delay time is created in RC integrator circuit, then inverted and summed to original signal. Described circuit was used to delay rising edge of all PWM signals and thus we need install them four times. The BTS780GP heated and diagnostics signals ST1 and ST2 occurred when dead time was shorter.

We made an experimental prototype of described subsystem for first set of tests without its load (sliding door). Then we compiled ADuC812 running program based on event rules programming. The program is running in waiting loop after initial conditions setting. External service interruption breaks the program if any event occurs. Then the program solves particular event according to the priority evaluation.

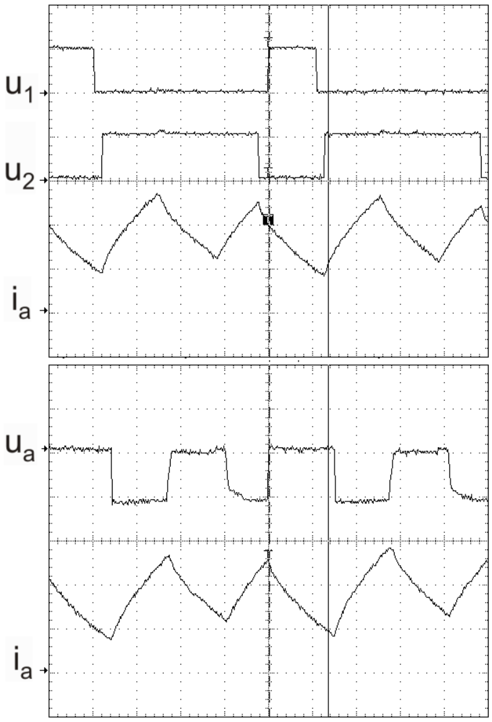

Fig. 3: PWM control signals, motor armature voltage and current

The pulse width of the used HEDR 542 encoder output signal is inversely related to rpm of the Valeo DC motor. This pulse width is measured by ADuC812 internal counter and the final value is rpm inverse value. Certain minimal pulse width is needed for rpm stabilization. This procedure just simplifies complicated computing algorithm of the door motion.

Designed system worked very well and we were able to measure motor speed-torque characteristics when the motor was PWM supplied from the 12 Volts DC power supply, see dashed line in Fig. 4 ($\gamma T=0.9*2.5$ ms). Then we moved the subsystem to the commercial hall to try its operation with real load. The first problem related to the mass of the sliding door occurred – the move of the sliding door was “lazy” and sometimes start procedure didn’t work.

We had to increase both power supply and backup battery voltage to meet the load torque, see example of 20 Volts marked by solid line in Fig. 4 (γT=0.9*2.5 ms). It is also possible to compare DC motor speed-torque characteristics for PWM supply (see solid lines in Fig. 5) with speed-torque characteristics for conventional 24, 20, 16, 12 and 8 Volts supply (see dashed lines in Fig. 5).

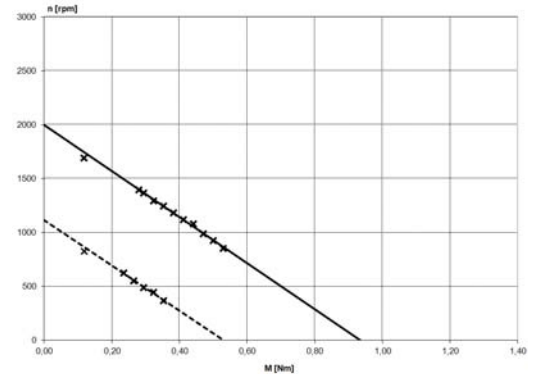

Fig. 4: DC motor speed-torque characteristics – PWM supply

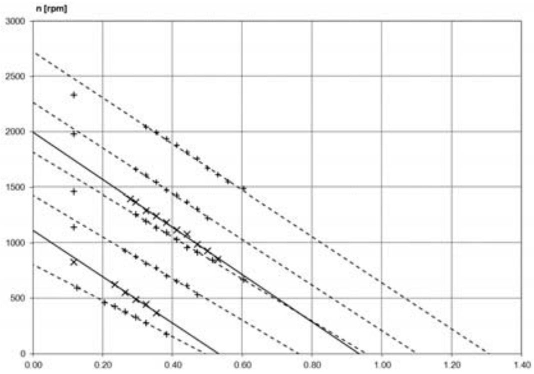

Fig. 5: Comparing PWM supply and conventional supply

Motion control algorithm

Stabilization of the door motion velocity is shown in Fig. 6. The information of door motion (Door_Close and Door_Open) is derived from PWM pulse width for BTS780GP power module. Difference between measured (HEDR 542 signal) and wanted (entered from user PC via USB interface) door motion velocity is com-puted (K_Ot_delta) to create control deviation (O_Ot_delta). Maximal control de-viation (PWM__step_max) is used if the computed difference (K_Ot_delta) is higher than set value (K_Ot_max).

We need to know plus or minus sign (plus_minus) to change PWM pulse width for BTS780GP power module correctly. For example, we need to slow down when the door is being opened and the measured door motion velocity is higher than wanted – the PWM width would be shorter (PWM_minus_step). We also need slow down when the door is being closed and the measured door motion velocity is higher than wanted but PWM width would be longer (PWM_plus_step) in this case. This interesting fact is caused by unipolar PWM generation unit [2] where the PWM duty cycle of the full bridge power transistors is 0.5 when DC motor shaft doesn't rotate. It is necessary to connect motor armature properly to the PWM driver or the program would not work.

Described program design can appear to be too much complicated but all instructions are written in assembly language and therefore the use of the classic mathematical operation is not possible. Use of the programming language C would simplify program design but there is problem with the control processor internal memory space. ADuC812 has only 2 kB memory space for program and it was really tough task to prepare designed program according to it.

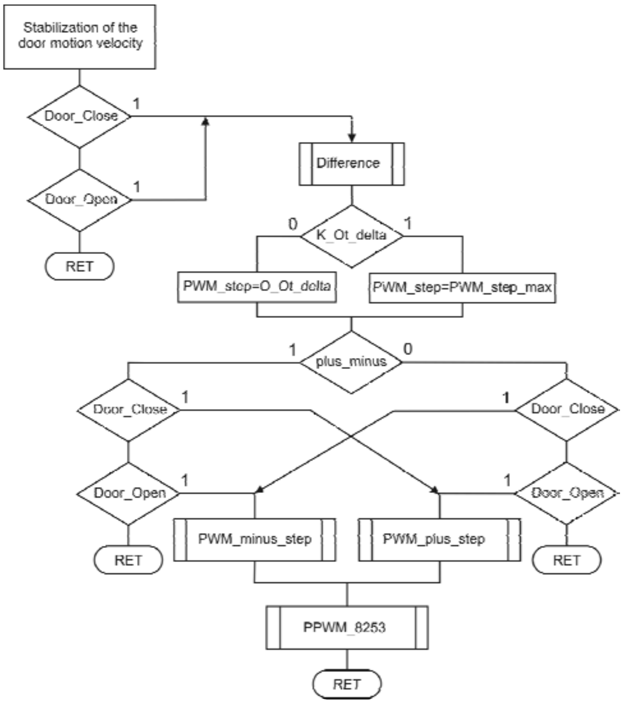

Fig. 6: Stabilization of the door motion velocity

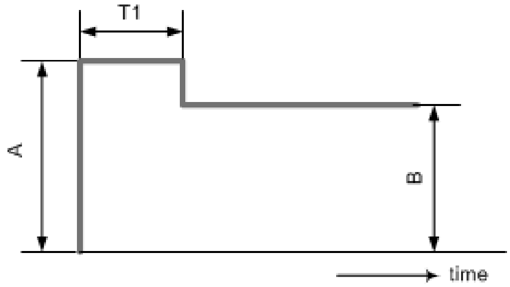

Fig. 7: PWM start algorithm

We compiled special PWM start algorithm for better door acceleration according to the Fig. 7. Higher motor armature voltage (A) causes motor torque high enough to speed up start procedure. Motor armature voltage is set to the final value (B) after T1 time. Final motor armature voltage is related to the wanted motor rpm value (door move) and the program for the stabilization of the door motion velocity is launched.

The program for the stabilization of the door motion velocity is stopped when the door passes the sensor S1 and the motor armature voltage is set to the zero for T2 time. Power MOSFETs are switched the same mean before and thus motor current flows the same direction. The motor armature voltage is set to the C value for T3 time and the motor acts in counter current braking mode. Then the motor armature voltage is set to the zero again for T4 time. The last section of the algorithm consists of D voltage value for the rest of the algorithm time to assure slow safe move to the sensor S2 where the motor is switched off.

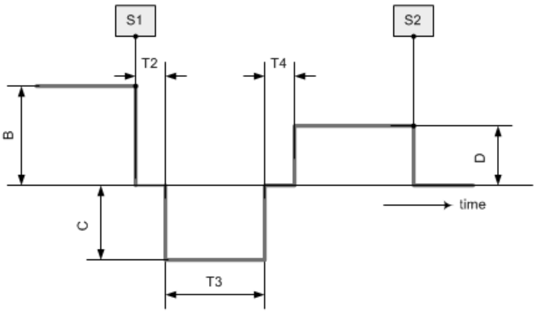

Fig. 8: PWM slow down algorithm

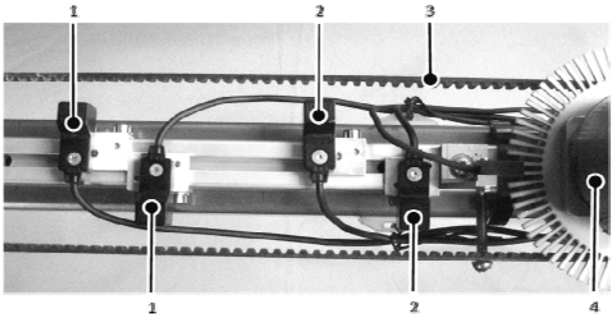

Fig. 9: Mechanical design (top view) – slow down (1) and stop (2) inductive proximity sensors, toothed belt (3) and Valeo drive (4)

Conclusion

The use of the PWM control of DC motor is one of the modern approaches to the motion control of the electrical drives. To carry out particular tasks from theoretical knowledge can sometimes cause practical problems. The functionality and running of designed primary system was verified during several hours of testing.

Application of microprocessor technology to the PWM control allows the same hardware design to be used to perform different software function. Three different algorithms have been performed - constant speed stabilization, start and slow down.

Designed primary system can be also easy modified to implement more sensors. The compiled ADuC812 program based on event rules programming would only be extended with another event processing.

It is also possible to chain the primary systems to control several independently opened doors according to the customer requirements. The same hardware use then also reduces total costs of designed system.

Designed PWM control system can also drive another DC drive. Power limits are then given by parameters of used PWM power module BTS780GP. It is possible to use any DC drive with armature voltage up to 40 Volts, armature continuous current up to 15 Amperes and armature peak current up to 30 Amperes. PWM signal frequency has to be less than one Kilohertz due to active freewheeling of the BTS780GP high side switches.

The work presented in this paper has been supported by the Ministry of Defence of the Czech Republic (K206 Department development program “Complex aviation electronic system for unmanned aerial systems”).

REFERENCES

[1] WILSON, Dave. Motor Control Compendium [online]. URL: http://focus.ti.com/download/trng/docs/c2000/TI_MotorControlCompendium_2010.pdf

[2] VALENTINE, Richard. *Motor Control Electronics Handbook*. New York: McGraw Hill, 1998. ISBN 978-0070668102

[3] LEONHARD, Werner. *Control of Electrical Drives.* 3rd edition. Berlin: Springer-Verlag, 2001. ISB 3-540-41820-2.

[4] DUB, Michal – JALOVECKÝ, Rudolf. PWM Controlled DC Drive with ADuC812 Microcontroller. In *Recent Advances in Mechatronics 2008-2009.* Berlin: Springer-Verlag, 2009, p. 269-274. ISBN 978-3-642-05021-3.

[5] DUB, Michal – JALOVECKÝ, Rudolf. Design and development of commercial door control system based on single chip microprocessor. In *Proceedings of the 4th International Symposium „Advances in Mechatronics 2009“.* Brno: University of Defence, 2009, p. 64-70. ISBN 978-80-7231-714-1.

[6] PECHLANER, A.; KERN, H.; AUER, F.: Throttle Control with Smart Power Bridges and Microcontrollers of the C500 and the C16x-families. System Engineering Automotive Application Note SE0899.

***Authors**: prof. Ing. Rudolf Jalovecky, CSc., University of Defence, Kounicova 65, 66210 Brno, Czech Republic, E-mail: rudolf.jalovecky@unob.cz; Ing. Michal Dub, Ph.D., University of Defence, Kounicova 65, 66210 Brno, Czech Republic,E-mail: michal.dub@unob.cz.*