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MICROPROCESOR MODEL TO CONTROL ZI MOTORS

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Summary. The paper presents an idea of a model of an electronic control unit based on a microcontroller AVR by ATMEL. The type used in tests is ATmega32. Its internal memory is sufficient to create and test single and composed algorithms. The model is able to change its software quickly, which is very important for the shortening of design processes. The exemplary software has been created for the controller in C language. The application of LCD display enables an observation of input and output signals and the co-ordination with board computers or any other external readout for the purpose of communication with OBD (On Board Diagnostic) systems.

Key words: ignition control, filling control, electronic control unit, ignition map, injection map, control algorithms for spark ignition motor

INTRODUCTION

An increasing number of produced cars and stricter environment protection rules force a strong competition among manufacturers. This induces a higher quality of both the whole vehicles and their sub-systems. A particular role belongs to electronics, without which meeting the environment protection requirements and introduction of driving safety improvements could be difficult to imagine. Even average class cars have such devices as: air conditioning, electrically lifted windows, electrically heated seats and mirrors, ABS, ESP systems etc. These devices increase electric energy demand. The important role in electric equipment in cars is played by microprocessor controllers. They enable controlled combustion processes of fuel – air mixture in cylinders. This contributes to lower use of fuel, optimization of torque, increased motor efficiency and reduced emission of toxic compounds to the environment. The application of microprocessor controllers gives additionally a possibility to monitor and test sensors, executive systems, emission control, creation of communication network and car diagnostics. All microprocessor controllers must have proper controlling algorithms to compute necessary parameters to control executive systems, on the basis of the data from board sensors.

MICROPROCESSOR MODEL

The basis for the construction of each microprocessor system is a microprocessor of data transfer velocity proportional to computational functions performed in the system and to the number of operated external devices.

The microprocessor model of a ZI motor controller has been constructed on the basis of a micro-controller type ATmega32 AVR by ATMEL. Its modern RISC core structure has been decisive for this application and also some other aspects such as: the most of arithmetic operations is performed in 1–2 cycles, the technical documentation is available, there is a wide choice of software tools, the programmer construction is simple and enables ISP (In System Programmable).

The constructional idea of the system is presented in Fig. 1.

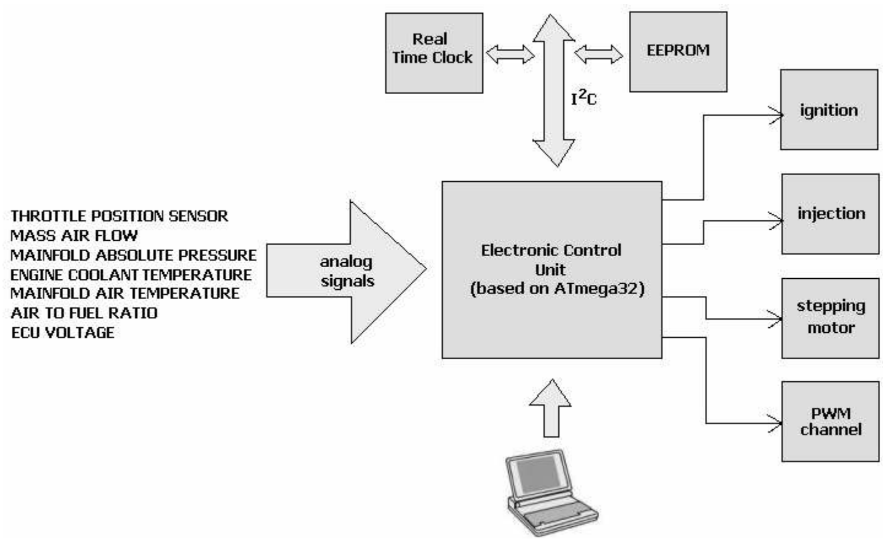

Fig. 1. The flow chart of the microprocessor model

The model enables an introduction of any input parameters for the motor, such as: throttle opening angle, rotational velocity, cooling liquid temperature, inlet air temperature, lambda probe voltage, controller supply voltage. Moreover, it enables users to observe in real time the influence of those parameters on the system response in the form of injector opening time and spark lead angle. Computers can be used in optional modifications of software and make possible to test new control algorithms.

ATmega32 is an 8-byte micro-controller of AVR type. The chassis contains 32 kb FLASH (10 000 cycles of save/delete), 1024 byte EEPROM (100 000 cycles of save/delete) and 2 kb of operational memory. Moreover, it gives a possibility to use four 8 – byte in/out ports, two 8 - byte timer/counters and one 16 – byte ones, which gives in total 4 modulation channels for pulse width PWM. The micro-controller has equipment interfaces, type: I^2C, SPI and emitter/receiver of serial transmission type: USART. It is also equipped by the manufacturer with a 10 – byte, 8 – channel analog-digital converter.

The model is equipped with the micro-controller and additionally with:

– an external serial memory EEPROM,

– RTC (Real Time Clock),
– ISP programmer to program the processor in the system through a SPI interface,
– LCD 4×20 for visual observations of inputs and responses during the system operation,
– a stepper motor to simulate a bypass air valve,
– d.c. motor controlled by the modulation of pulse width PWM (e.g. a cooler fan, a fuel pump),
– controls to signal the current operation state.

CONTROL ALGORITHMS

The motor control software consists of many different procedures and functions that can be divided into:

Strategic procedures – steer the system in given operational conditions established on the basis of board sensors. They are multi-purpose and can be used in similar types of motors

Sperational procedures – they contain data tables and functions and are used for a particular motor type. They are introduced to the controller memory in the form of two-dimensional or three – dimensional tables called maps. The algorithm computes basic parameters on their basis (injector opening time, spark lead angle) and correct these parameters. The form of applied operational procedures depends on the used micro-controller and the environment).

Tool procedures – are responsible for the service of input and output signals. They contain: initiation procedures, diagnostic procedures, input procedures such as: analog signal measurements and rotational velocity measurements; output procedures such as: bypass valve operation for air inlets or throttles, injectors, ignition system and other executive elements; mixed procedures such as the operation of transmission connections RS-485, CAN.

The steering programs are usually created by means of C/C++, which eases and speeds up the process. It is necessary to know the micro-controller construction and the user has access to ready-made mathematical procedures and functions connected with the processor registers.

The presence of the breaker system of a micro-controller gives possibility to optimize velocity and the sequence of performance of particular parts of the steering program. The more important algorithms will be operated within the breaks of higher priority, and the less important ones during lower priority breaks.

The steering program of the constructed controller is in C language. It consists of the series of sub-routines that enable the choice of one among five modes of operation. The available modes are the following:

MODE 1 (current parameters) – the most important mode, enables the simulation, inputs and observations of diagnostic parameters in real time (inputs and values computed by the steering program) and simultaneously the breaker operation of external executive systems. Moreover, it enables checking signals from sensors. In the case of an erroneous signal a proper error code is generated and saved as a so called frozen frame in the external EEPROM memory.

MODE 2 (a frozen frame) – since an error occurs and the error code has been saved in the EEPROM memory, this mode enables observations of time and date of occurrence and also system operational parameters at that moment.

MODE 3 (deleting error codes) – this mode shows the quantity of errors kept in the external EEPROM memory and enables deletion.

MODE 4 (testing of executive elements) – the user can test external executive systems, i.e.: the stepper motor of the additional air valve on idle run (the settings enable 3 types of the stepper motor control) and a d.c. motor controlled by PWM modulation (4 modulation frequencies are available).

MODE 5 (settings) – this mode enables: the synchronization of a RTC clock with the current time, the choice of one from three control types of the stepper motor and the choice of one from four operational frequencies of the PWM modulator that controls the d.c. motor, e.g. to control the cooler fan.

The following equations of interpolation polynomial have been applied in the algorithms:

– In the cases of urgency characteristics for the spark lead angle and the opening time of the injector, there is one-dimensional Lagrange's interpolation:

$$W(x)=\sum_{i=0}^{n} y_i \frac{\prod_{j\neq i}(x-x_j)}{\prod_{j\neq i}(x_i-x_j)}, \quad j=0,1,\dots,n$$

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where:

x – current rotational velocity,
x_i, x_j – table values of rotational velocity,
y_i – table values of the spark lead angle or injector opening time,
W(x) – interpolation polynomial value (calculated the spark lead angle/injector opening time) at given rotational velocity, x.

– In the case of spark lead angle map and injector opening time map – two-dimensional interpolation (Fig. 2):

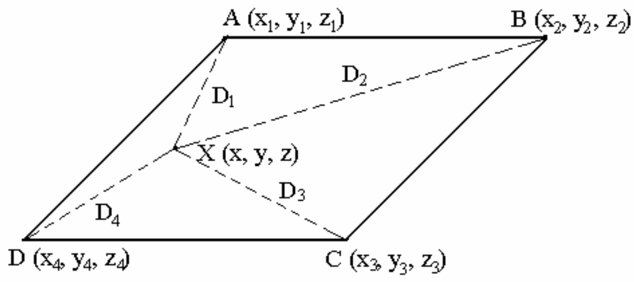

Fig. 2. The principle of two-dimensional interpolation
A, B, C, D – rastar's node co-ordinates (x, y, z),
D_1, D_2, D_3, D_4 – node distances from the point
X, X – the point of known x, y co-ordinates and z co-ordinate

The equation of the third co-ordinate of X:

$$z_X = \frac{\sum_{i=1}^{4} z_i \cdot \frac{1}{D_i^2}}{\sum_{i=1}^{4} \frac{1}{D_i^2}} \tag{2}$$

where:

$$D_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{3}$$

The equation has the final form:

$$z_X = \frac{\sum_{i=1}^{4} z_i \cdot \frac{1}{\left(\sqrt{(x - x_i)^2 + (y - y_i)^2}\right)^2}}{\sum_{i=1}^{4} \frac{1}{\left(\sqrt{(x - x_i)^2 + (y - y_i)^2}\right)^2}} \tag{4}$$

where:

x_i – table values of rotational velocity,
y_i – table values of throttle opening time,
x – current rotational velocity,
y – current value of throttle opening time,
z_i – table values of the spark lead angle or injector opening time,
z_X – the result of two – dimensional interpolation – the calculated value of the spark lead angle or injector opening time on the basis of table values for four nodes.

The algorithm of computation of the spark lead angle is presented in Fig. 3.

The exemplary regulation characteristics in a table form have been introduced to the internal FLASH memory in the micro-controller, i.e.: spark lead angle map (Fig. 4) and injector opening time map (Fig. 5). Additionally, correction characteristics have been introduced (e.g. Fig. 6), to determine, in some conditions, the correction of two main parameters. The control algorithm computes signal values from external sensors and determines the control parameters on their basis, i.e. spark lead and injection time. The algorithm of two-dimensional interpolation has been applied to increase computational precision and to reduce memory occupied by the data (Fig. 2). The algorithm executes efficiency tests for the sensors, too.

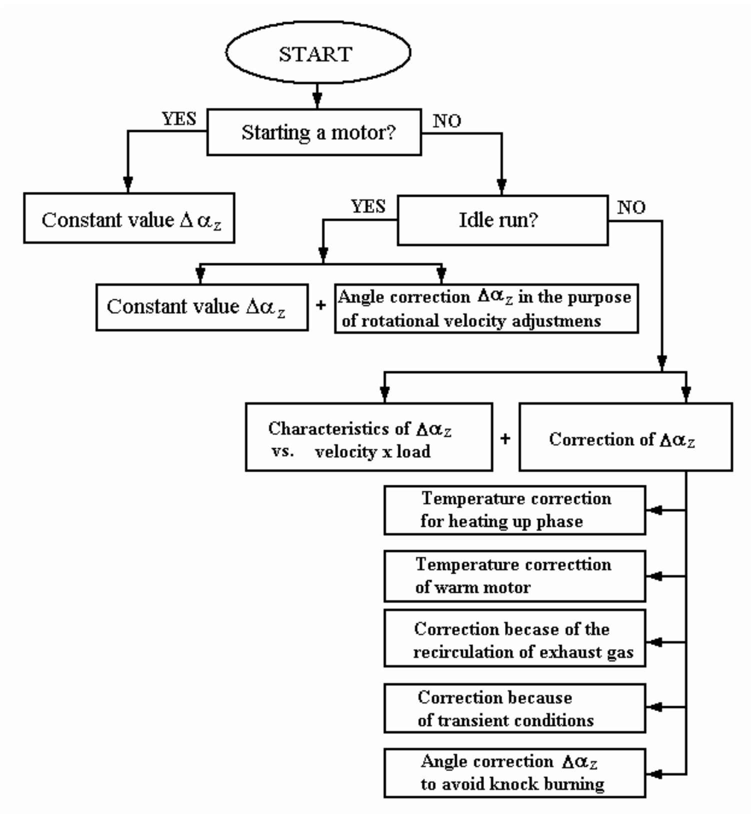

Fig. 3. The scheme of computation of spark lead angle [Podleśny 2005]

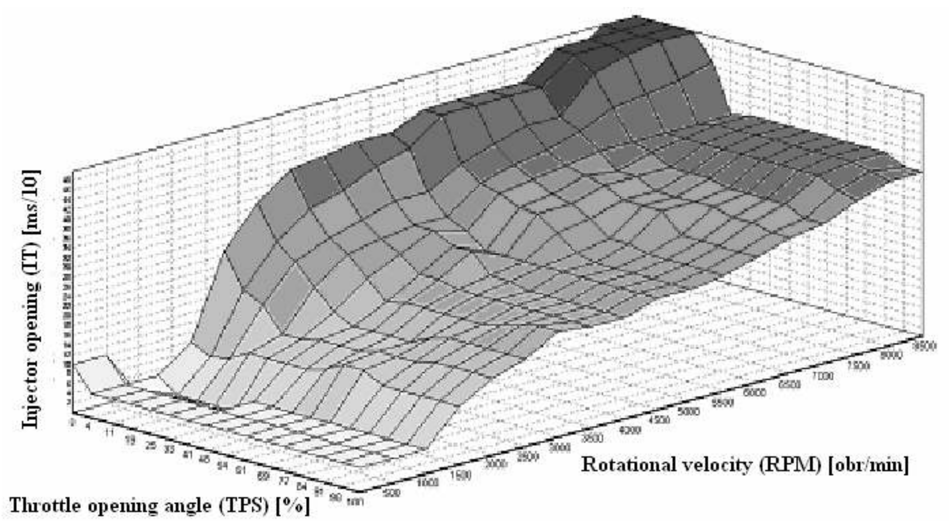

Fig. 4. Spark lead angle map [Soliński 2004]

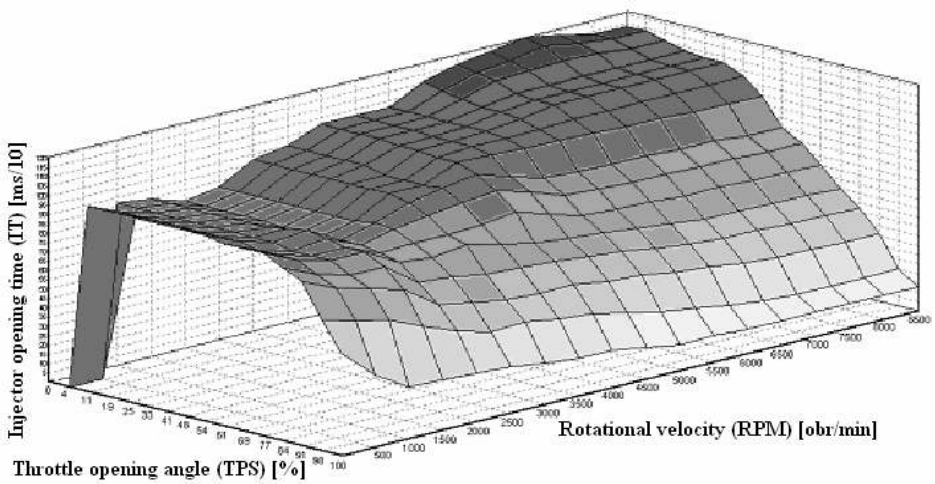

Fig. 5. Injector opening time map [Soliński 2004]

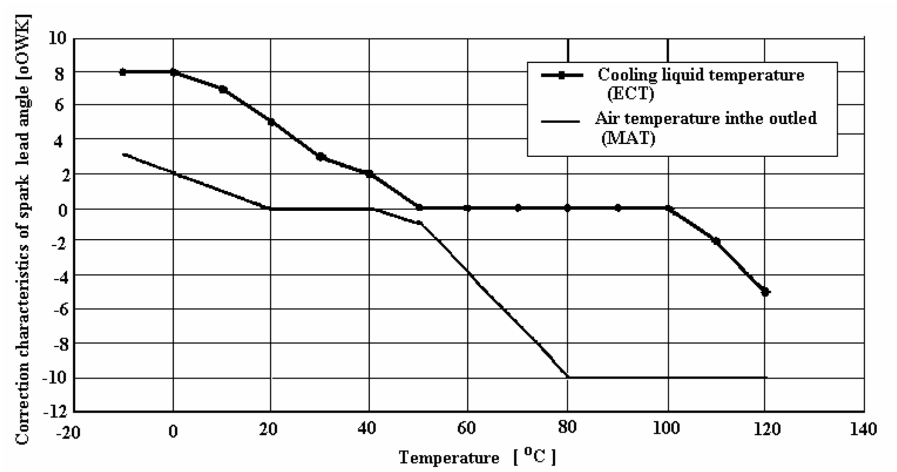

Fig. 6. Correction characteristics of spark lead angle vs. cooling liquid temperature and air temperature in the inlet

In case of damage to the motor load sensor, the control system can change the characteristic into the one – dimensional urgency one or it can adapt the equivalent load value to the computations. The urgency values usually mean a much longer ignition delay. Fig. 7 presents exemplary parameters during the system operation in MODE 2 and 3.

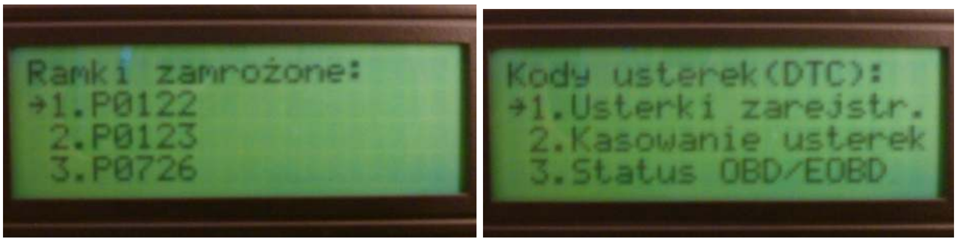

Fig. 7. The exemplary parameters during the system operation in MODE 2 and 3 (registered errors) P0122 – low signal of the level sensor of throttle position TP, strategy: urgency characteristics A, the lamp MIL lights, P0123 – high signal of the level sensor of throttle position TP, strategy: urgency characteristics B, the lamp MIL lights, P0726 – motor velocity inlet circuit RPM – signal beyond the range, strategy: RPM = 8500 rpm, the lamp MIL lights

CONCLUSIONS AND REMARKS

The designed and constructed microprocessor model enables:

1) simulations in real time of control algorithms of a spark ignition engine
2) changes of basic and correction parameters of operation of a fuel engine,
3) simulations of sensor accidental damages,
4) registration of error codes and frozen frames,
5) simulations in real time of control algorithms of executive systems,
6) an application of the real microprocessor model to the creation and tests of control algorithms of a fuel engine makes it possible to reach higher reliability of results in comparison to the computer simulation of the controller.

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