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Vehicle Stability Control (VSC) and Supervision based on CAN network: Part II

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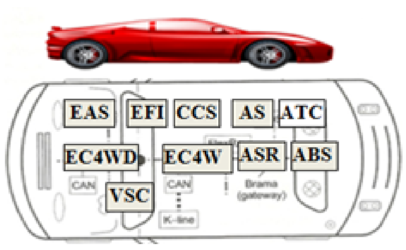
***Abstract*—High reliability and velocity of on-board computers (CAN+, FlexRay) enable monitoring and controlling, in real time, various events related to vehicle motion. This article includes an example of control process related to ESP (Electronic Stability Program) subsystem.**

Concise ESP performance curve is followed by description of system control based on the controllers and CAN bus. At the end, an example of low-power actuator system control versus parameters requested with keyboard or random number generator, which simulates events in real time, is described.

***IndexTerm* - CAN C+ operation analysis, ESP system, control systems, on-line control in ESP/VSP system, low-power actuator system on-line control.**

I. INTRODUCTION TO ESP

ELECTRONIC Stability Program (ESP) is a system that constitutes a part of Advanced Vehicle Control systems. It is a supervision system, used for keeping the track by the vehicle, and one of several vehicle control systems that are installed in contemporary vehicles most frequently. (Fig. 1)



ABS Antiblocking Braking System
AS Active Suspension
ATC Automatic Transmission Control
ASR Acceleration Slip Regulation
CCS Cruise Control System
EAS Electronically Assisted Steering
EFI Electronic Fuel Injection
EC4WS Electronically Controlled 4Wheel Steering
EC4WD Electronically Controlled 4Wheel Drive
VSC Vehicle Stability Control - and so on..

Figure 1. Typical vehicle control system in a contemporary vehicle. (Based on [1])

The joint feature of all foregoing systems is ability to control running gear of the vehicle in motion. Its on-line adjustment of enlisted systems' settings should be quick and reliable.

ESP is a control system which major role is to keep the track, in the course of turning and taking control over ABS and ASR in order to enhance traction at the same time. ABS system is to control wheel blocking during heavy braking, and ASR system is used for monitoring and preventing against wheel spin at sudden steep steer turn.

The reasons for faults during vehicle's travel may be over-speed, week tractive adherence, and steep steering wheel movements at passing stationary obstacles. As a result, excessive slip of wheels occurs causing oversteering and understeering. **Understeering** occurs when front axis looses its adherence to the tract and is subject to side drifting.(Fig.2 A) Angle of drift on front wheels increases quicker than angle of drift on rear wheels. Then the vehicle swings out. **Oversteering** (Fig.2 B) is related to rear axis which adherence at particular moment is insufficient to counterbalance side centrifugal force. Unbalanced centrifugal force causes excessive rotation of the vehicle on its axis (angle of drift on rear wheels increases quicker than on front wheels). [2]

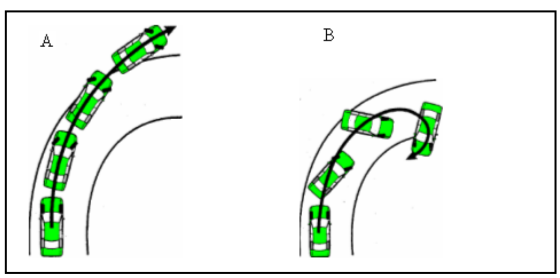


Figure 2. A- Understeering, B- Oversteering [2]

In cases that have been analysed, ESP system operation includes detection of deflections from correct, intended track and its correction by brakes operation and motor control board[1]. It means that ESP system uses functions of ABS and ASR systems to correct the track in its operation. However, it is only a part of ESP operations. In order to ensure vehicle stability in critical situations, (e.g. oversteering or

[1] Motor adjustment shall be understood as adjustment of choke valve angle

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understeering), ESP uses also motion properties that determine the states of the entire vehicle and other features like individual wheel slipping in critical situations. Vehicle's motion properties are obtained as a result of plenty of tests, (e.g. Moose Test), which allow determination of stability, steering control, braking efficiency, vehicle's conduct in case of slipping.

All obtained data are used for both optimisation the vehicle's motion properties and engineering the track stabilisation system for particular vehicle's model. One of the major test results that supported the development of the track stabilisation is the relationship of angle of side drift that is dependent on magnitude of forces occurring on the vehicle, acceleration force, braking force, adherence, centrifugal force at turning, side acceleration, as well as determination of situations when the vehicle demonstrates tendency for over- or understeering. All these conditions determine track stabilisation for a particular model. These data are stored in control system memory.

A. Electronic Stability Program - operation

ESP function is to monitor continuously values measured by gauges for the vehicle movement, (Table 1a includes measured values), and compare those values to the parameters requested by the driver (Table 1b). As soon as the potential hazard of vehicle's control loss is detected VSC (Vehicle Stability Control) system triggers the vehicle's motor (*choke valve cut-off*) and brakes individual wheels in order to keep the track. ESP system activates itself automatically, slowing down one or couple of wheels when a suitable gauge senses the tendency to slip the vehicle off the turn. Control algorithm by ESP, shown in Fig. 3, explains its operation.

TABLE 1A.
PARAMETERS DETERMINING STATE OF THE VEHICLE MOTION

Measured values	Calculated values
1. angular velocity	1. longitudinal velocity
2. angle of rotation of steering wheel[2]	2. forces occurring on wheels
	3. wheel slip
3. transverse acceleration	4. wheel drift angle
4. wheel rotational speed	5. vehicle drift angle
5. braking pressure	6. vehicle's transverse acceleration

TABLE 1B.
PARAMETERS REQUESTED BY THE DRIVER

Parameters requested by driver
1. angle of rotation of steering wheel
2. estimated travel speed
3. position of brake pedal (fluid pressure in brake master cylinder)
4. position of acceleration pedal

ESP system continuously measures parameters of the vehicle in motion and checks differences between requested and real angular velocities.

[2] Measures in bolds spot the reader's attention on the relationship between those measures and the movement of steering wheel and x - by –wire systems

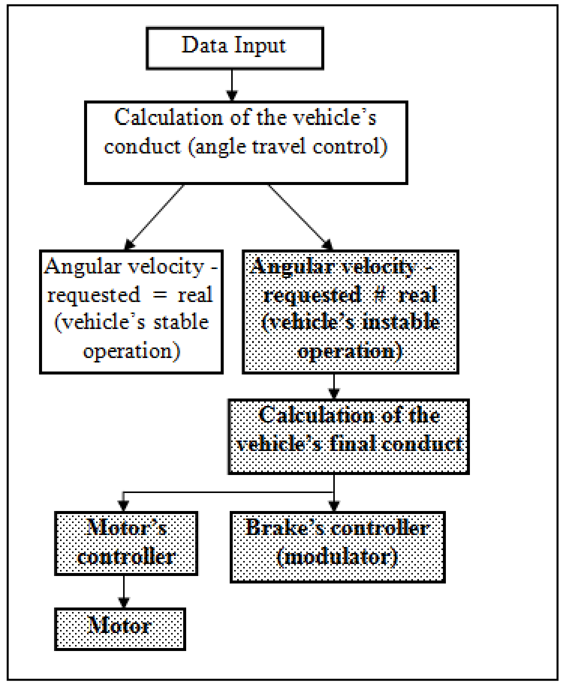

Figure 3. General operation of ESP system

If those values differ, consecutive measurements are carried out and immediate correction of motor and brake controller operations are implemented.[2]

B. ESP controller

The controller is equipped with flash memory, in which the program is stored. Adjustment and factory data for various models of vehicle, pre-configured for specific model, are stored in EPROM. RAM is used for storing temporary data that are required for current calculations.

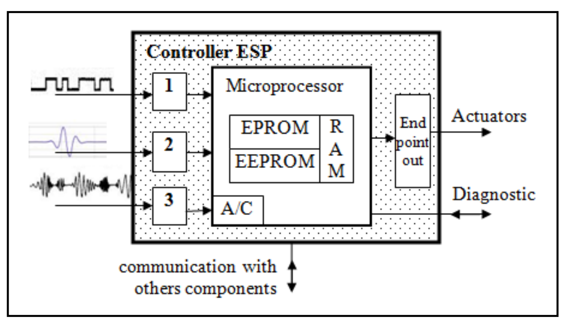

Figure 4. ESP controller internals. (Based on [2])

Analogue signals are transferred to the controller input (e.g. pressure at brake master cylinder), then converted into digital signals in A/C converter. **Digital** signals, e.g. from steering wheel movement sensor, and **pulse** signals, from rotational speed sensor, are filtered from interferences and directly used for calculations. The program that is stored in the controller's memory uses both current values, read at the controller's input, and a set of adjustment values stored in EEPROM and EPROM. Calculated setting values, upon amplification in final step amplifier, are controlling signals transferred to actuators (e.g. valves controlling brake fluid pressure).

II. ELECTRONIC STABILITY PROGRAM - VSP

Coupling ESP controller to subassemblies used for monitoring stability of the vehicle in motion is shown in Figure 5.

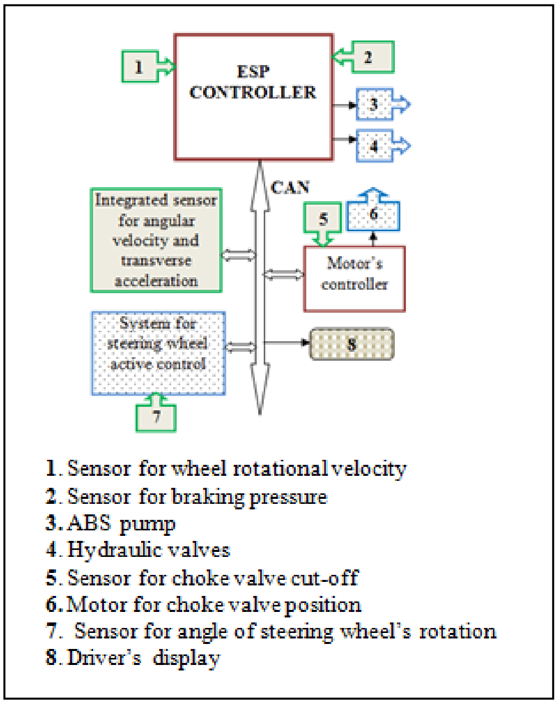

Figure 5. VSC including input systems (According to [8])

It should be noted that the sensor for wheel rotational velocity (1) and the sensor for braking pressure (2) are directly connected to ESP controller by-passing CAN bus.

Measured changeable data received by velocity sensor are read almost continuously. It would have affected the bus operation for the majority of time. Direct signal provision to the input of ESP controller significantly enhances its reliability.

VSC (Vehicle Stability Control) system CAN network, shown in Figure 5, supports five major nodes, such as ESP controller, integrated sensor for acceleration and angular velocity, sensor for angle of steering wheel's rotation, motor's controller, dashboard (the source of information for the driver). The sixth user is the system for active control of steering wheel (DAS).

ESP controller and **motor controller** may both send and receive messages to/from CAN bus. However, the sensors transfer merely values of measured parameters to the bus; whereas, informations for the driver are transferred just to the dashboard. Within VSC systems, arbitration[3] issue is related to the following types of messages:

-- Request from ESP controller to the motor's controller for input of choke valve position alteration. (This information is of a high priority as it has an impact onto alteration of the vehicle's motion);

-- Messages from the motor's controller to ESP controller related to choke valve position.

-- Sending measured data from integrated angular velocity and acceleration sensor. (Priority of this message is quite high. On the basis of these data, calculation of controlling parameters for ESP system, including ABS, ASR4 and MSR5, is carried out.

-- Sending measured data from the sensor for angle of steering wheel's rotation. These data include information related to motion direction requested by the driver. (These data are used to determine the driver's intentions and calculate distribution of the vehicle's load and its acceleration vector).

-- Messages for the driver are displayed on the dashboard.

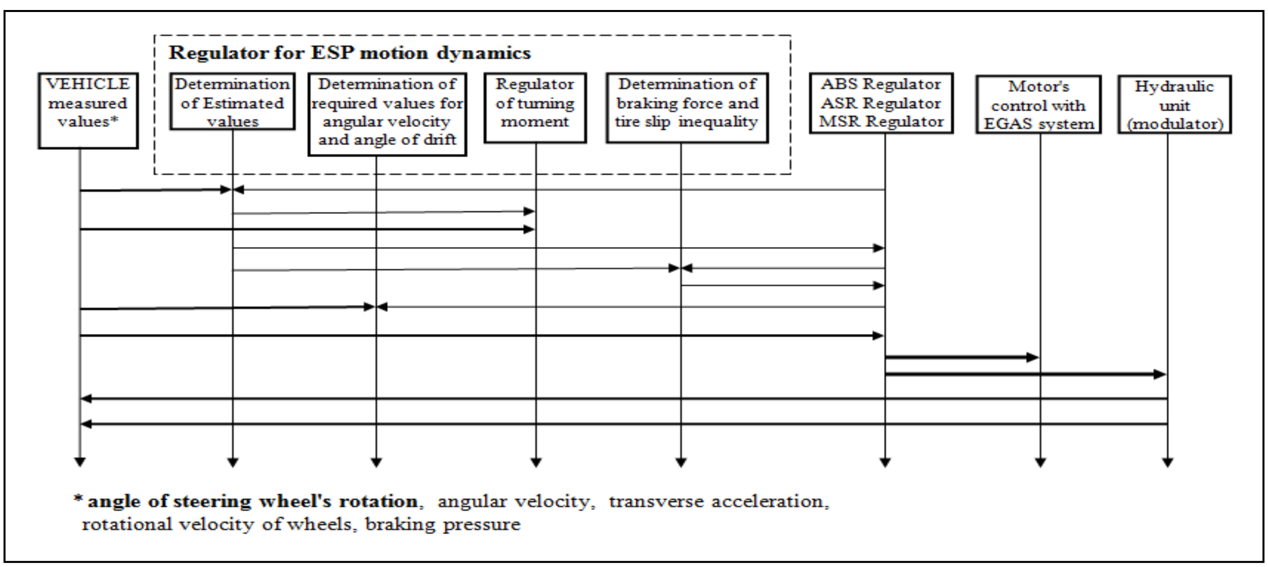

Figure 6. Diagram of VSC system states

[3] Arbitration issue is detailed in [3]
[4] ASR - Acceleration Slip Regulation
[5] **MSR** is a supplementary system for ASR. It reduces turning moment of the motor during downward change and prevents against adherence loss.

The major signals from ESP controller, sent to pressure modulator, are forwarded without use of CAN bus (Fig. 5). All remaining data that are necessary to complete control algorithm are available through CAN bus. Information related to the vehicle's condition and the driver's[6] intentions are compared within the controller to the values stored in its memory. As a result of this comparison, the controller carries out with suitable corrections. The diagram for states of the system, which is analysed, is show in Fig.6.

III. CONNECTION AND TRANSMISSION IN CAN NETWORKS

From among two methods of information exchange between drivers[7] in CAN networks, a method of directing the message content [3] is used in analysed case. Owing to this fact, better data consistency is obtained thus decreasing bus load. Directing the message content requires, however, recognition of hundreds if not thousands of identifiers for various messages by controller. That is why transmission controllers are pre-configured, hardware managed, in a way as to enable recognition of appropriate messages only. Additionally, suitable bit masking[8] is applied to enable filtering group addressing one bus only (here: power transmission system)[9]. (Specified hardware managed mechanisms enable significant shortening of time for appropriate messages recognition and detection).

Directing the message content (CAN 2.0A and CAN 2.0B) includes also prioritising[10] the transferred data. A specific example of a message is, so called, remote message that requires transfer of data from the other controller (addressed in the message). Request message does not include any operational data; however, addressed controller recognises the request directed through RTR field[11] of the message (RTR is set as dominant) [3].

In order to exchange some information between controllers, it is required to set-up dynamic link (channel), which upon completion of transmission is removed on every occasion. Upon channel set-up, the controllers exchange messages in the form of transmission frames between themselves. (Figure 17, 18 in Part I of the article [3]). Demonstration transmission course including direction of the message content, shown in Figure 8, is implemented with the application of system SO4204-7K Lucass Nuelle laboratory station, Figure 7.

6 Data read by the sensor for angle of steering wheel's rotation inform about the driver's intention

7 (1) It is a method for directing the number of receiving devices and a method (2) for directing the message content (e.g. the message includes information related to the motor's rotational velocity useful for selected recipients only).

8 Bit masking enables blocking specified bit configuration. Data filtration is shown in Figure 13 in part 1 of the article [3].

9 Grouping address constitutes logical sum of the primary identifier and a single address for all bus controllers.

Types of buses and links are described in [4].

10 A role of information priority in the access to the bus is specified in [3].

11 SSR bit is an equivalent of RTR for response [3].

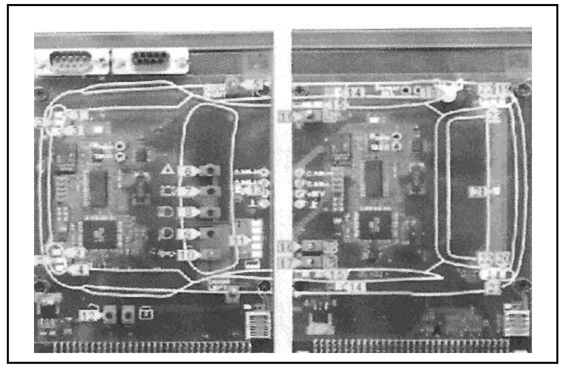

Figure 7. SO4204-7K Lucass Nuelle laboratory station [7]

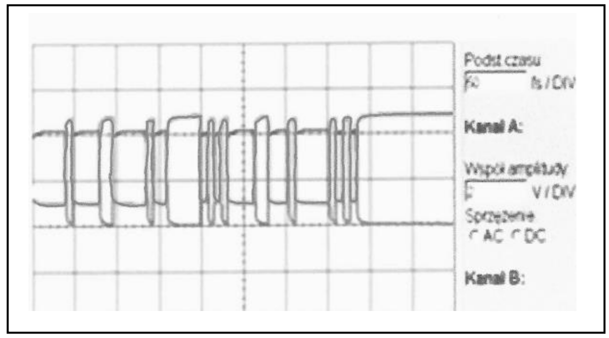

Figure 8. Example of the message transmission within CAN bus [7] (Switching on the braking light)

IV. EXAMPLE OF OPERATION SYSTEM CONTROL

Controlling low-power operation system is shown in Figure 9. Requested control curves are shown in Figure 10. Random number generator, for simulation of real system, is used as transmitter for requesting control parameters. Control parameters may be also entered directly by the user through interface shown in the subsequent figures. 8051 family system is used as major controller and stepping motor EDS10 is used as executive system.

The system has been developed for the needs of testing laboratory as part of the course of *Vehicles' Computer Systems* subject run by the author.

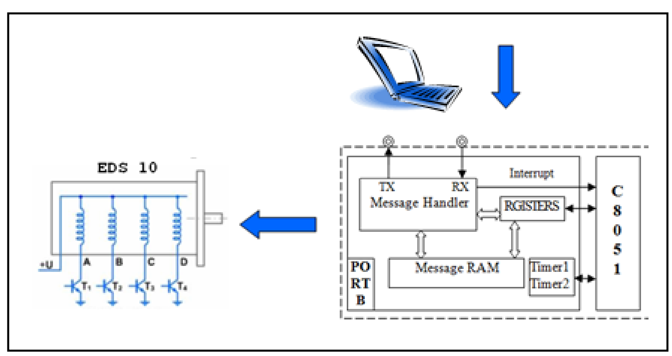

Figure 9. Control by 8051controller with stepping motor EDS10

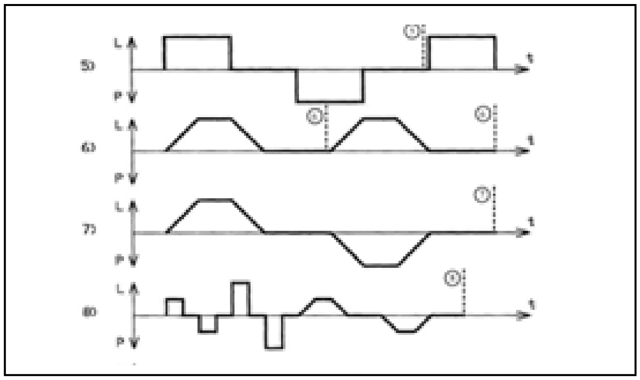

Figure 10. EDS10 control curves

Described control was completed in 3 modes.

Mode 1 Requesting control parameters through computer desktop by the user. In this mode, the user provides values such as motor rotation direction (simulation of choke valve opening or closing), rotational velocity (choke valve cutting-off/closing) and selects one of four control bands as starting band (simulation of current position of the choke valve)

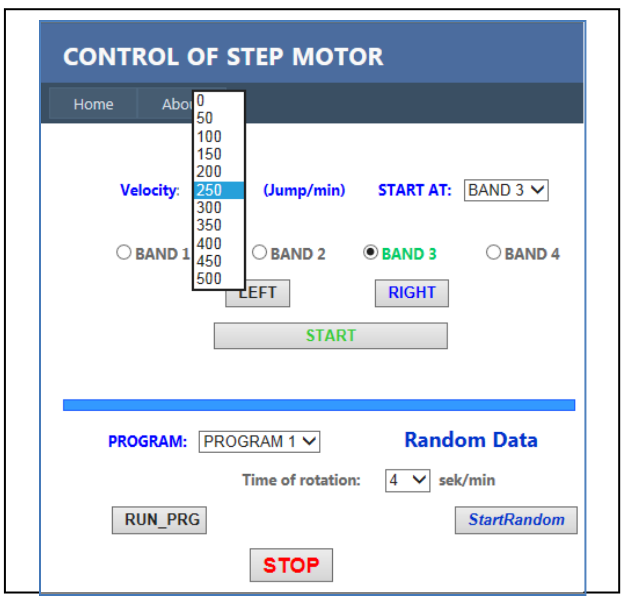

Figure 11. Control parameters requested by the user through interface [12]

Mode 2 Selection of control curve from among 9 available options (Compare to Figure 10).

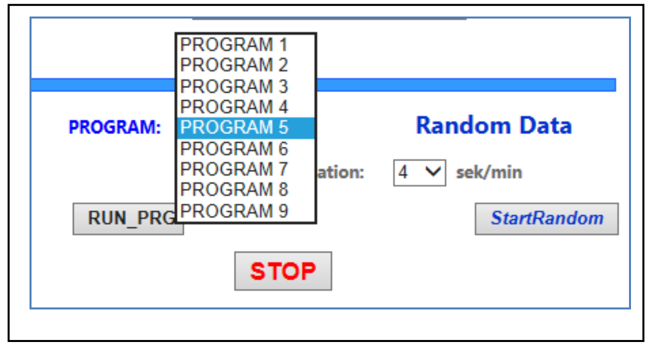

Figure 12. Excerpt from UI including selection of control curve number

Mode 3 Application of random number generator for control alternatives, e.g. spin direction (0.1), spin velocity (1 to 5) x 10 rpm, and spin time (4 to 20) [s].

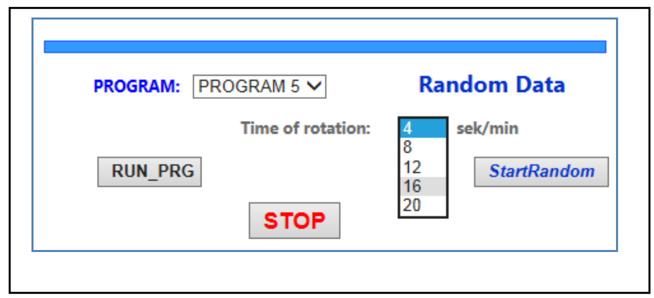

Figure 13. Excerpt from UI including control parameter requested by random number generator.

Specific motor bands, Fig. 9 (transistors T1, T2, T3, and T4), are controlled by 4 bits from port B of 8051 controller to which following control codes are transferred[13]:

ZERO	EQU	0000 0000B	STOP;
ONE	EQU	0000 0010B	BAND1;
TWO	EQU	0000 1000B	BAND2;
THREE	EQU	0010 0000B	BAND3
FOUR	EQU	1000 0000B	BAND4;

Control registers store defined values of motion parameters such as:
R4 – time-constant for uniform motion; R5 – time-constant for uniformly accelerated motion, R6- time-constant for uniformly retarded motion; R7- time of requested motion; R8- adjusted time for motion arrestment; RI – register for signalling termination of data collection (1).

Coded operation procedure, for the motor that has been analysed, is as follows: low/high right turns; low/high left turns; uniformly accelerated left/right motion; uniformly retarded left/right motion, and operation procedures supporting interruptions: stop/start the motor.

All data are stored in the memory of microcontroller. Upon completion of data input, (through random number generator or keyboard), microcontroller port with its operation system is

[12] UI software was implemented by the author in Visual Studio 2010 by Microsoft. EDS10 motor control was carried out in 8051 family microcontrolling assembler [5, 6].

[13] These codes correspond to state of tension on port B input

commanded. Owing to sequence supply to consecutive bands, the motor rotor rotates at requested frequency[14] to the left or right.

CONCLUDING REMARKS

The rules for information exchange, monitoring, and control in vehicle's on-board network, which have been described above, show that these networks are able to effectively solve complicated and complex control algorithms in on-line mode. DAS (Direct Adaptive Steering) systems constitute the next example of substituting material system with mechatronics systems in which the major part forms digital systems and IT solutions.

Direct adaptation control (steer-by-wire) is a sheer transfer of data, related to impact of the motion of steering wheel onto turning wheel with application of highly sensitive actuator, through electronic system. These data, similarly to the other sets of data, are captured by ESP systems for preservation of vehicle's motion stability. Owing to steer-by-wire solution, material loss, causing attenuation in efficiency and reaction deceleration in standard systems, are eliminated. It is another proof for appropriateness of implementation of intelligent digital IT solutions that replace mechanical solutions.

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[14] 4 red LEDs, placed in motor casing, light up and go out in sequence showing motor's band admission. The arrow that is linked to the rotor shows direction of revolutions