THEORETICAL VERIFICATION OF VEHICLE SUBSYSTEMS APPLIED WITH CAN BUS AND PRINCIPLE OF ENGINE ECU MONITORING .

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Abstract. *Instead of mechanical systems, the new vehicles become advanced mechatronics systems whose development and testing call for a new approach. The possibility of using data available on the vehicle network presents itself as an extremely powerful tool.*
This paper deals with a new approach to service load data measurement and acquisition as a helpful tool in developing and testing of different mechatronics vehicle systems. The new approach is based on a hardware and software platform oriented to main vehicle controllers with the task to acquire relevant transmission service load data. The hardware as well as software utilities have to enable computer-based monitoring of the vehicle systems behaviour and thus they should be the tool for new vehicle development.
The new system was tested in real service. The system significantly lessened time of vehicle instrumentation before testing and enabled accurate data acquisition.

Key Words: *Vehicle, CAN Bus, Service Load, Engine Monitoring, Electronic Control Unit*

1. INTRODUCTION

One of the most important factors affecting the development of a new product, including its testing, is the duration of development activities. It is of great importance to reduce the time from the initial technical specification of the new product to the moment of launching its serial production. This task is mainly an obligation of the development engineers who are under great pressure to meet market-driven demands for a fast and reliable new product design.

It is important to note that many vehicles, which are in service, already have installed advanced mechatronics systems. This fact enables the development team to use the exist-

ing vehicles as a platform for acquiring the service load which would serve as reference input for designing the new vehicle. Simply speaking, collecting the service load through standard vehicle electronics enables faster and more reliable new product development and validation.

The system which is developed for service load data acquisition on vehicles fitted with the CAN bus is presented in the following section.

### 1.1. Can-based system for service load data acquisition

The concept of the system is based on a common situation in present-day vehicles already fitted with electronic networks which are in use for data interchanging among different vehicle's controllers and their instruments (Fig. 1 - top). In spite of the fact that there are a few protocols which are in use on vehicles' networks it should be noted that all of them are mainly based on the same physical layer which is widely accepted by all producers. This physical layer is defined by ISO 11898 or frequently named as CAN 2.0B. As seen in Fig. 1 - bottom, all data which have to be transferred through this layer have to be organized in frames which start with SOF (Start of Frame) character, followed by 29 bits CAN identifier, RTR character, Control Field, 0 to 8 byte Data Field, CRC Field, Acknowledge Field and EOF (End of Frame) bits.

From the message format it is clear that data of interest to the service load would be placed in Data Field. But, to be in position to use this data a few problems have to be solved. Those problems are mainly related to the CAN identifier (ID).

As is defined by ISO 11898 CAN ID has to be 29 bits long. Yet different protocols use that identifier in different ways. For transmission load investigation it is of importance to be oriented to the protocols which are dominant for engine and transmission controllers. As per situation in the market those controllers are mainly based on SAE J 1939 protocol. SAE J 1939 is a protocol with all 7 layers, but for the first two layers (lower two layers) it takes definition from ISO 11898 i.e. CAN 2.0B bus. Before establishing data acquisition from CAN bus what should be analyzed is the way in which SAE J 1939 uses CAN's identifier (Fig. 2b). In brief, in J 1939 the first 3 bits of ISO 11898 Identifier (ID) are in use for priority (000 for the highest priority and 1111 for the lowest priority). The next 18 bits are in use for PGN or Parameter Group Number.

The PGN is the key element for understanding possibilities for service data acquisition from the existing vehicle's network. All the data sent to the CAN bus are organized in the groups. For example, all data relevant to the electrical transmission controller would be placed in the data message (according to the SAE J 1939 terminology: PDU i.e. Protocol Data Unit) in which PGN would be 61442 and 61445. Data available in messages (i.e. messages Data Fields) with PGN(s) 61442 and 61445 would be: transmission selected gear, transmission actual gear ratio, percent of clutch slip, transmission input shaft speed, etc. It is clear that lot of data significant for transmission service load are already available on the vehicle bus in the messages with appropriate PGN's.

Out of data messages with PGN(s) related to the transmission controllers, there are other messages of interest. Those are mainly the messages from engine electronic controller, retarder controller, axle controller, etc.
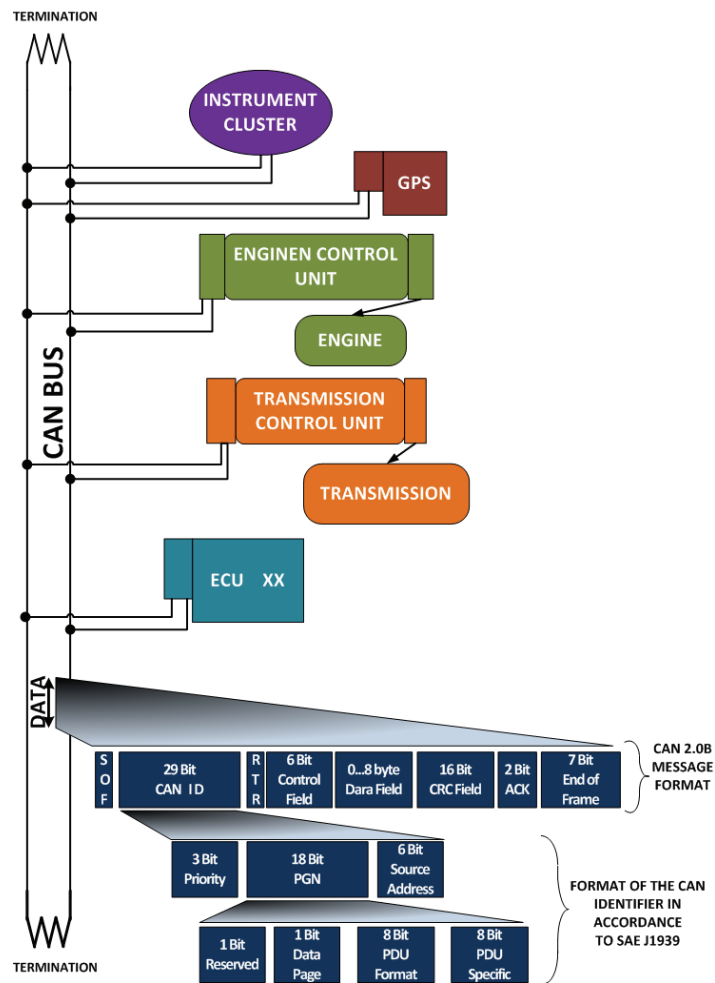
Fig. 1 Common configuration of the vehicle's CAN bus (top) and the message format (bottom).

To understand the concept of service load data acquiring it is essential to be familiar with the PGN concept. Unfortunately, the concept of PGN and establishing CAN identifier is not as simple as stated above. Strictly speaking, PGN has 4 parts: Reserved bit, Data Page bit, PDU Format - 8 bits and PDU Specific - 8 bits. Also, it has to be noted that PDU Specific can be defined in two different ways based on the value of PDU Format: as the Destination Address (for PDU Format values 0 to 239) or as Group Extension (For PDU Format values 240 to 255). All of this makes the approach to the messages on the CAN bus (PDU) very complicated and can cause a lot of problems.
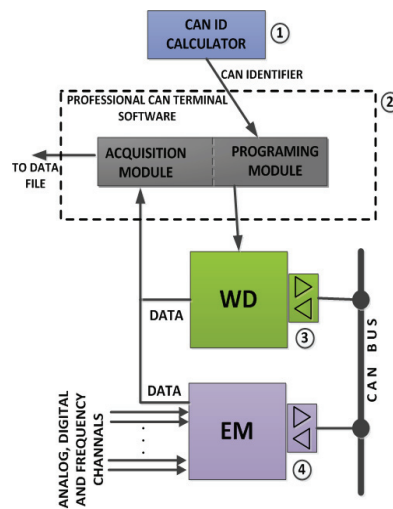
Fig. 2 Hardware and software components developed through the project
(meaning of numbers and abbreviations are given in the text)

As previously explained, defining the proper PGN is not sufficient for successful data acquisition, i.e. acquiring data of interest from the CAN bus. It is also important to know the position of the value of interest in Data Field. The Data Field is 8 bytes long and encloses different data. Their allocation in Data Field must be known for proper data extraction.

Based on the explained concept of data flow through CAN bus it is obvious that first interest in establishing the system for data acquisition has to be oriented to providing for adequate software tools for PGN, CAN Identifier (ID) and Data Field evaluation.

To reduce problems, i.e. to enable easier service data acquisition through CAN bus the project whose results are given in this paper take into consideration the development of several software and hardware components which are listed below.

1. CAN Identifier (ID) Calculator – software component,
2. Professional CAN Terminal – software component,
3. Watch Dog (WD) – hardware component, and,
4. Extension Module (EM) – hardware component.

The scheme of functional interdependence of the developed components is given in Fig. 2 where components are marked with appropriate numbers as given above.

The first of the developed components is "CAN identifier (ID) Calculator", with the structure as in Fig. 3. Through various data bases it provides support in defining CAN identifier from different standards including SAE J 1939. The user can access the date base trough Excel (Fig. 3, path marked with 1). The data base can be searched in different ways including searches based on data of interest such as engine torque, engine rpm, etc. In that way, the user can find the value which he is interested in to monitor or to acquire from the bus. Once when the value of interest is defined the software defines PGN and other parts of 29 bit identifier (Fig. 3, path marked 3) in accordance to the previously explained rules. In this way, the user is in position to know which message has to be grabbed

from the communication on the CAN bus and to be in position to extract appropriate value(s) from the data field in that message (i.e. from PDU).
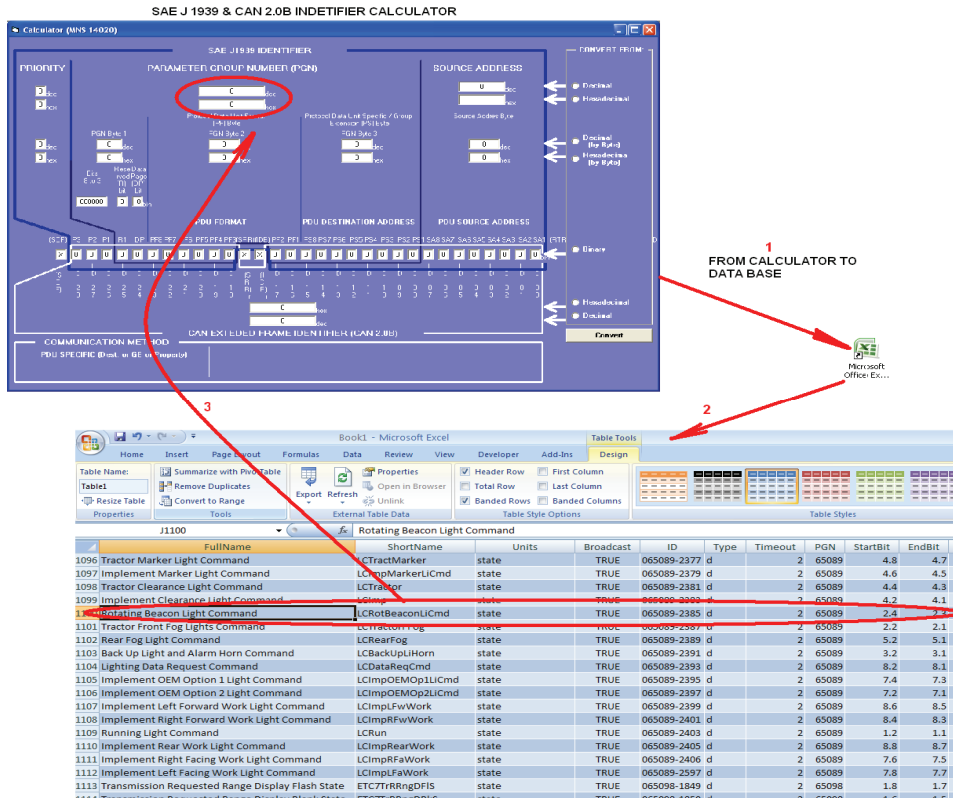

	FullName	ShortName	Units	Broadcast	ID	Type	Timeout	PGN	StartBit	EndBit
1096	Tractor Marker Light Command	CTractMarker	state	TRUE	065089-2377	d		2	65089	4.8	4.7
1097	Implement Marker Light Command	LCImpMarkerLiCmd	state	TRUE	065089-2379	d		2	65089	4.6	4.5
1098	Tractor Clearance Light Command	LCTractor	state	TRUE	065089-2381	d		2	65089	4.4	4.3
1099	Implement Clearance Light Command	LCImp	state	TRUE	065089-2383	d		2	65089	4.2	4.1
1100	Rotating Beacon Light Command	LCRotBeaconLiCmd	state	TRUE	065089-2385	d		2	65089	2.4	2.3
1101	Tractor Front Fog Lights Command	LCTractorFFog	state	TRUE	065089-2387	d		2	65089	2.2	2.1
1102	Rear Fog Light Command	LCRearFog	state	TRUE	065089-2389	d		2	65089	5.2	5.1
1103	Back Up Light and Alarm Horn Command	LCBackUpLiHorn	state	TRUE	065089-2391	d		2	65089	3.2	3.1
1104	Lighting Data Request Command	LCDataReqCmd	state	TRUE	065089-2393	d		2	65089	8.2	8.1
1105	Implement OEM Option 1 Light Command	LCImpOEMOp1LiCmd	state	TRUE	065089-2395	d		2	65089	7.4	7.3
1106	Implement OEM Option 2 Light Command	LCImpOEMOp2LiCmd	state	TRUE	065089-2397	d		2	65089	7.2	7.1
1107	Implement Left Forward Work Light Command	LCImpLFwWork	state	TRUE	065089-2399	d		2	65089	8.6	8.5
1108	Implement Right Forward Work Light Command	LCImpRFwWork	state	TRUE	065089-2401	d		2	65089	8.4	8.3
1109	Running Light Command	LCRun	state	TRUE	065089-2403	d		2	65089	1.2	1.1
1110	Implement Rear Work Light Command	LCImpRearWork	state	TRUE	065089-2405	d		2	65089	8.8	8.7
1111	Implement Right Facing Work Light Command	LCImpRFaWork	state	TRUE	065089-2406	d		2	65089	7.6	7.5
1112	Implement Left Facing Work Light Command	LCImpLFaWork	state	TRUE	065089-2597	d		2	65089	7.8	7.7
1113	Transmission Requested Range Display Flash State	ETC7TrRRngDFlS	state	TRUE	065098-1849	d		2	65098	1.8	1.7
1114	Transmission Requested Range Display Blank State	ETC7TrRRngDBlS	state	TRUE	065098-1850	d		2	65098	1.6	1.5

Fig. 3 CAN Calculator; top – the software structure; bottom – the monitor page which provide support to the user to calculate CAN ID based on SAE J 1939 protocol

Since data is organized in 8 bytes Data Field, successful monitoring requires knowing the position of the data of interest within Data Field: the last two columns in the data base (see Fig. 3, columns marked with "StartBit" and "EndBit"). In this way the first software component developed in this project provides the user with full support related to the messages on the CAN bus even without his deep knowledge of the protocols.

The next part of the data acquisition system developed for the project is dedicated hardware (see Fig. 4 - top), named WD. WD is a Watch Dog type hardware with the following basic specification:

- Microprocessor based mother board,
- 128 dedicated memory slots,
- Two CAN based gates,
- One Ethernet gate,
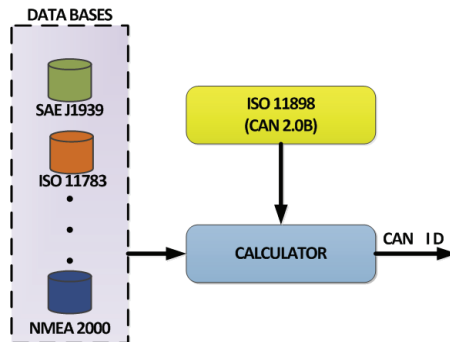
▪ Memory block for application programs, etc. (see Fig. 4 – top).
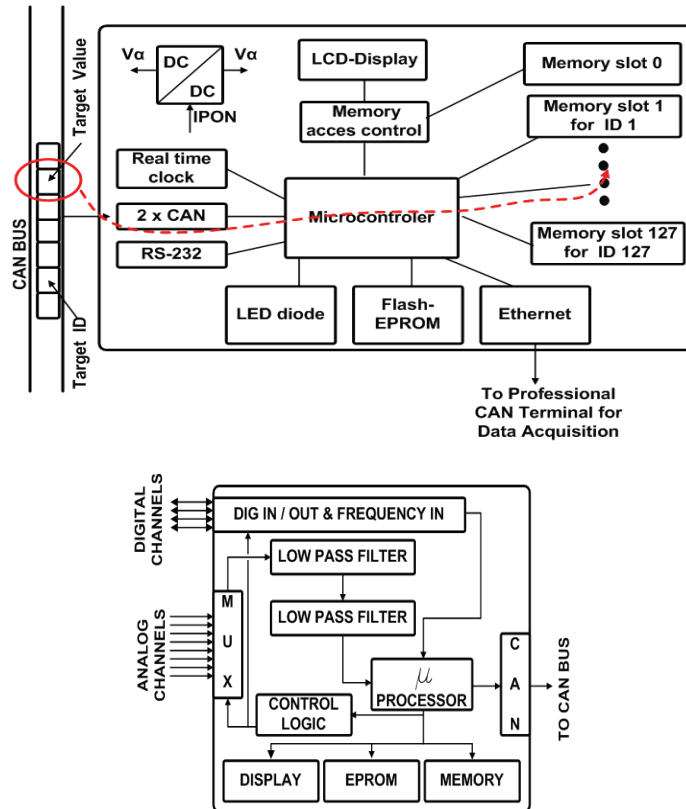
Fig. 4 Configuration of the hardware components: top – WD (Watch Dog);
bottom – EM (Extension Module)

The WD hardware is initially programmed with parameter free software developed in this project. The software drives WD to continuously listen the traffic on the CAN bus. Once WD gets started it will ask for parameter values. These values enable WD to know

CAN identifier(s) of interest and parts of the data field that have to be extracted from the message with defined identifiers. It also makes it possible to know from which memory slot to download the extracted value. This process is visualized with red lines in Fig. 4 (top) and explained in more details and through examples with transmission related data, later in the text (see Fig. 7 and text in the section III).

Once the user defines all the parameters, the WD will grab data of interest from the CAN bus and place values of interest in memory slots. The on-line monitoring and data acquisition of the values are available through the Ethernet gate.

The third part of the developed system is software which enables WD programming, on-line data flow monitoring and data storage for post acquisition evaluation. That software product, named "Professional CAN Terminal" (main user page of the software given in Fig. 5) has specification as follows:

- Automatic allocation of WD within local network,
- Definition of parameters which defines data of interest from CAN bus,
- Monitoring of ongoing communication in real time and data storage, and,
- Possibility of sending messages to the CAN bus.
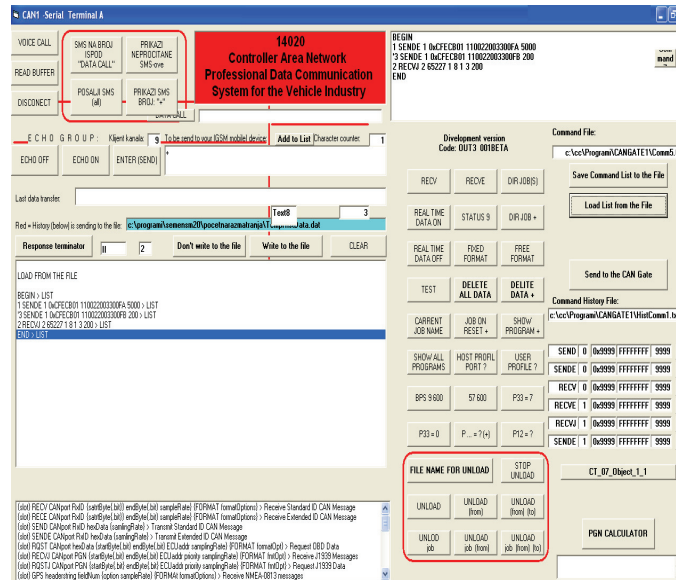
Fig. 5 "Professional CAN Terminal" software – the main monitor page

The second hardware component developed in this project is "Extension Module" or EM (the configuration given in Fig. 4 – bottom). The EM, among other things, performs two essential services:

- Analog to digital conversion of the analog values, and,
- Broadcasting CAN based messages with converted values.

The necessity for the module development comes from the unavailability of all values of interest on the CAN bus. It's quite common for some values of interest for acquisition

not to be broadcasted on the vehicle's CAN bus. In such cases there are two possibilities for acquiring data of interest: (*i*) to use separate (additional) data acquisition system or *(ii)* to provide the system which will measure the value(s) of interest and make up the PDU(s) with Data Field in which data of interest (measured values) would be incorporated. The latter method has several advantages. It enables utilization of the already existing data acquisition system which is oriented to the CAN bus, for acquisition of all needed data and it makes needless any additional measurement and acquisition unit.

In this project the latter of the two above mentioned approaches is used.

3. CAN BASED SYSTEM APPLICATION

As noted in the introduction, one of the important advantages of data acquisition through CAN bus is to provide for accurate service load data for the system which has to be developed, by using the data from the already existing systems. This section deals with that kind of the new data acquisition system application, i.e. its application in designing a tractor transmission.

For the purposes of designing the new agricultural tractor transmission it is necessary to make a detailed investigation of gear box input power (actual input rpm and torque) as well as front and rear axle input toque and rpm. All those data are needed as an input for precise design calculation of the new tractor transmission.
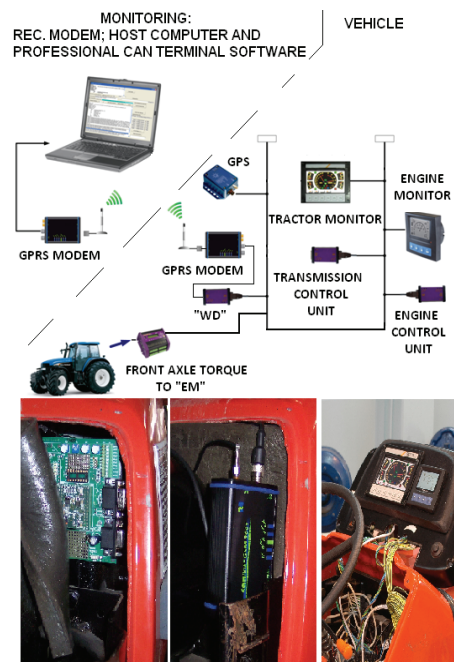
Fig. 6 System for service load data acquisition trough CAN bus: top – configuration of the system, bottom left – EM built in the tractor; bottom middle – GPRS modem built in the tractor, bottom left – installation of the WD unit

A tractor already on the market, with specification similar to that of the new tractor which had to be developed, was used. Since the existing tractor was "CAN based" it was cost and time effective to provide transmission service load data by utilization of CAN based data acquisition system. Consequently, it was possible to avoid making the prototype of the new tractor for the purpose of service data investigation.

The existing tractor was instrumented in the way that WD was installed on its CAN bus (see Fig. 6). For real time data monitoring WD's Ethernet port was connected to Ethernet port of a GPRS modem i.e. a data channel was set up from CAN bus to GPRS network. Monitoring station was fitted on the local computer with Professional CAN Terminal software and with another GPRS modem (receiver).

For acquiring data which were of interest for this investigation and which were found as missing in CAN bus traffic (broadcasted by no one ECU on the network) the Extension Module (ED) was connected to the bus. Since the front axle input torque was a not-broadcasted value of interest the additional front axle torque measurement line was established on tractor's propeller shaft and the analog signal from the toque conditioning unit was directed to the EM.

Before data acquisition, it was necessary to find appropriate PGN(s) part of Data Field in PDU(s) and ID for the values of interest. That was done with previously developed CAN Calculator software. The following text gives in detail explanation of that process. Given explanation is of general importance since it provides guidance for other researchers and facilitates their work on data acquisition through CAN bus.

For the engine speed which is (when the vehicle's clutch is engaged i.e. while the transmission is loaded) equal to the transmission input speed, the relevant PGN is 61444 and 2 bytes long data of engine rpm starts in 4th byte in Data Field. It was found that engine control unit on the tractor had address 0. Based on SAE J 1939 i.e. with help of CAN Calculator software it was found that corresponding CAN identifier of interest is ID = $00DE0400_{hex}$. The whole process can be visualized as in Fig. 9 and is symbolically represented as follows:

Engine speed:
Priority Level: 3 >>> ID = $011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61444_{dec} $00F004_{hex}$= $xxx001111000000000100xxxxxxxx_{bin}$
Source: 0_{dec} = 0_{hex}= $xxxxxxxxxxxxxxxxxxxx00000000_{bin}$
Result ID = 217056256_{dec} = $00DE0400_{hex}$
Start position in Data Field: 4th byte
Length: 2 byte
Note: "x" replaces 0 or 1 i.e. bit can be set or reset.

The next value of interest is engine torque or transmission input torque which is broadcasted by the engine electronic controller with the same PGN. The calculated output torque of the engine is transmitted as indicated torque in percentage of reference engine torque. Consequently, CAN calculator software found that the ID of the message which contents data relevant for torque was 217056256_{dec} or given in-deal:

Engine torque
Priority Level: 3 >>> ID = $011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61444_{dec} $00F004_{hex}$ = $xxx001111000000000100xxxxxxxx_{bin}$
Source: 0_{dec} = 0_{hex}= $xxxxxxxxxxxxxxxxxxxx00000000_{bin}$
Result ID = 217056256_{dec} = $00DE0400_{hex}$
Start position in Data Field: 2nd byte
Length: 1 byte

Even if the torque level is transmitted in percentage of reference engine torque the actual torque value can be easily find out. This is possible based on the engine characteristic which is always defined in ECU memory as rpm/torque matrix. The matrix can be given in one of three modes. Mode 1 provides a complete curve of speed and torque points while modes 2 and 3 provide a partial curve of speed and torque points and a separate end speed governor characteristic. Data from the matrix loaded in ECU can be acquired by sending the request with PGN 65251.

Here, the part in which the Professional CAN Terminal software was described has to be recalled. As is given in the software specification, its main purpose is to help in WD programming, to enable monitoring of the traffic on the CAN bus and to support data acquisition. But, as also mentioned in the software specification, it has a capability to send messages to the CAN bus. The purpose for sending message to CAN bus is to enable response with specific data (available in electronic control units) which are not broadcasted without specific request.

Before starting data acquisition it is essential to send request with PGN 65251 to CAN bus. That request would be served by engine control unit. The ECU will reply with a message with multi-data field (total length 39 bytes) which is matrix data. In this way we can find the torque value (in Nm). The actual torque level would be found based on torque value in percentage which would be transmitted with ID $00DE0400_{hex}$ as explained above and from the data which would be enabled through request with PGN 65251.

The next values of interest were actual or engaged gear ratio and actual transmission range. Taken together, these two values give information of overall transmission ratio. Both are defined in data field of the messages with the PGN 61445, as follows:

Transmission actual gear ratio:
Priority Level: 6 >>> ID = $110xxxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61445_{dec} $00F005_{hex}$= $xxx001111000000000101xxxxxxxx_{bin}$
Source: 2_{dec} = 2_{hex}= $xxxxxxxxxxxxxxxxxxxxx00000010_{bin}$
Result ID = 418383106_{dec} = $18F00502_{hex}$
Start position in Data Field: 2th byte
Length: 2 byte

Transmission current range:
Priority Level: 6 >>> ID = $110xxxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61445_{dec} $00F005_{hex}$= $xxx001111000000000101xxxxxxxx_{bin}$
Source: 2_{dec} =2_{hex}= $xxxxxxxxxxxxxxxxxxxxx00000010_{bin}$
Result ID= 418383106_{dec} = $18F00502_{hex}$
Result ID= 418383106_{dec} = $18F00502_{hex}$
Start position in Data Field: 7th byte
Length: 2 byte

In addition, data for real tractor speed needed to be provided. This is extremely important since there is no other way of finding out wheel slip (as a critical parameter for the differential lock design) out of measuring the real vehicle speed and each wheel rpm.

Real vehicle speed value, in nowadays tractors, is provided based on GPS based Doppler transducer which broadcasts measured value to CAN bus with PGN 65256 according to the concept given bellow. The priority and position of the data in data field are:

Navigation-Based Vehicle Speed (real tractor speed):
Priority Level: 6
ID=110xxxxxxxxxxxxxxxxxxxxxxxxx$_{bin}$
PGN:65256$_{dec}$= 00FEE8$_{hex}$=xxx001111111011101000xxxxxxxx$_{bin}$
Source: 10$_{dec}$ A $_{hex}$= xxxxxxxxxxxxxxxxxxxx00001010$_{bin}$
Result ID = 419358730 $_{dec}$ = 18FEE80A$_{hex}$
Start position in Data Field: 3rd byte
Length: 2 byte

A few other parameters, which are of minor interest for the paper, are also taken into consideration during the ED development but the same are not discussed here.

4. BASICS OF ENGINE ECU MONITORING

Electronic control unit (ECU) is the main regulatory body of the engine operations. It receives signals from various sensors that provide information about the engine operation regime; it processes these signals and accordingly sends an output signal to the elements (solenoids, actuators, etc...) that control the operation of the fuel injection system and a complete engine. One of the main ECU functions is to control fuel injection. The ECU processes the incoming signals from the external sensors and limits them to the permissible voltage level. A number of the incoming signals are also checked for plausibility. Using these input data, together with stored characteristic curves, the micro-processor calculates output value that is then converted into a characteristic signal. This calculation program is termed the "ECU software". The main signals to the ECU from various sensors are following:

- Engine speed signal from the sensor that accepts the impulses from engine crankshaft;
- Engine phase signal (signal of the position of engine working cycle) from the sensor on engine camshaft;
- Accelerator position signal as the information on necessary engine load;
- Fuel pressure signal as the information on high pressure after fuel pump;
- Boost pressure signal as the information on supply air pressure after turbocharger;
- Air temperature signal;
- Cooling water temperature signal;
- Intake air mass flow signal;
- Vehicle clutch engagement signal;
- Vehicle constant speed control signal;
- Vehicle air conditioning;
- Vehicle automatic transmission signal as the information on gear shifting;
- Vehicle braking system as the information on ABS activation;
- Vehicle speed signal;
- Parking or additional brake signal;
- Engine brake signal;
- Turbocharger speed signal, etc.
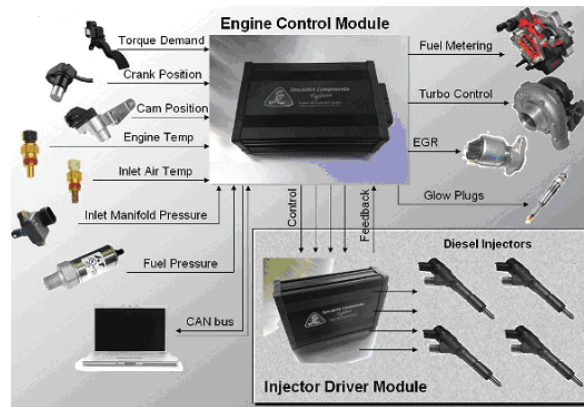
Fig. 7 Input and output signals from Engine Control Module (i.e. ECU manufactured by
Hurricane) to CAN bus microprocessor and Injection Driver Module for fuel injection

The received signals are processed in the ECU and eventually are compared with the de-
sired values from memory. An example of input and output signals from ECU is shown in
Fig. 7. The output signals are applied to output stages that provide adequate power for the
actuators (for instance the high-pressure solenoid valves for fuel injection, EGR positional,
or boost-pressure actuator). Apart from this, a number of other auxiliary-function compo-
nents are also triggered using incorporated CAN bus system. Used control functions in the
ECU depend on the engine application and scope and generally define following parameters:

- Fuel injection control during starting,
- Control of engine pre-heat through the glow plug during engine starting and warm-up,
- Control of injected fuel quantity depending on engine load,
- Limit of maximal injected fuel,
- Control of injection advance,
- Control of pilot and post injection,
- Control of injection pressure in high pressure lines,
- Control of boost pressure,
- Engine cooling control,
- Engine idle control,
- Engine speed limitation,
- Misfire recognition,
- Equalizations of cycle by cycle and cylinder by cylinder fuel injection quantity,
- Cylinders disengagement,
- Engine brake (retarder) control,
- Control of vehicle constant drive speed,
- Limitation of maximal vehicle speed,
- Control of engine smoke,
- Control of EGR system,
- Control of exhaust after-treatment system (SCR, particulate filter, etc.),
- OBD system,
- Communications through CAN bus system, etc.

In order to understand all the subsystems functioning, especially of CAN bus ECU i.e., Engine ECU (in Fig. 1 marked green as ECU to engine) we have to evaluate the management of engine ECU. ECU or Electronic Control Unit is a subsystem of engine electronic system regulation and control, where sensors receive all signals. The ECU represents a memory unit where engine exploitation data are gathered (load and torque); its signals are calculated and forwarded to actuators in order to regulate the engine injection time, air intake, etc. Modern electronic control units are quick in response considering the collection of large number of information inside and out of ECU in a short time. The number of parameters calculated by the Engine ECU is estimated approximately as 10000. Faulty signal characteristics are detected by the output-stage diagnosis functions. Furthermore, signals are exchanged with other systems in the vehicle via the interfaces. The engine ECU monitors the complete injection system within the framework of a safety concept.

Basically, the engine ECU is divided into three segments: Input signals are connected to sensors; before being forwarded to the microprocessor they are conditioned (amplified and filtered) and converted to analog signals, or to a form acceptable to the microprocessor (ADC). The program requires a microprocessor for processing the signals stored on the crucial components of the type of ROM or EPROM. For these components, they are stored in data type of regulation or control level, and constant values necessary for calculation of parameters of control and engine management. This allows that one electronic control unit with different contents of EPROM is used for different purposes for engine (coordination of variants). The RAM is stored in the data related to the results recalculation, correction factors or possible error information in the electronic system. This memory, unlike RAM, loses its contents with disappearance of the power supply. For output connectors, the microprocessor controls the output terminals. Output connectors are special electron loops that protect the engine against overload. Integrated diagnostic functions have the function to recognize that possibility, so if necessary, they can turn off the exit on which is the error data are observed. In this case, the program must start the principle function of ECU and protect the engine from damage.

The introduction of the engine regulation by a micro-processing system in a digital format brings a number of specific features and innovations.

Also, because of the independence of the mechanical engine components system, it is possible to establish the desired control algorithm. Regulators are no more susceptible to aging (no maintenance needed in terms of replacement of mechanical components), and monitoring of limit values can be exploited for diagnostic systems. In addition, it is possible to establish a system of multiple regulators of interrelated and to synchronize their work; thus, for example, the same signal distributed, at the same time, in different places, by different control units, makes it possible to achieve control (action) and to perform it because of the joint action of multiple regulatory circuits.

Regarding the system performance, digital controls that are implemented on vehicles, it can be concluded that the input signal quantization is usually done with an 8 bit analogue to digital converter, and the need for higher resolution and use the analogue to digital converters with 10 bits.
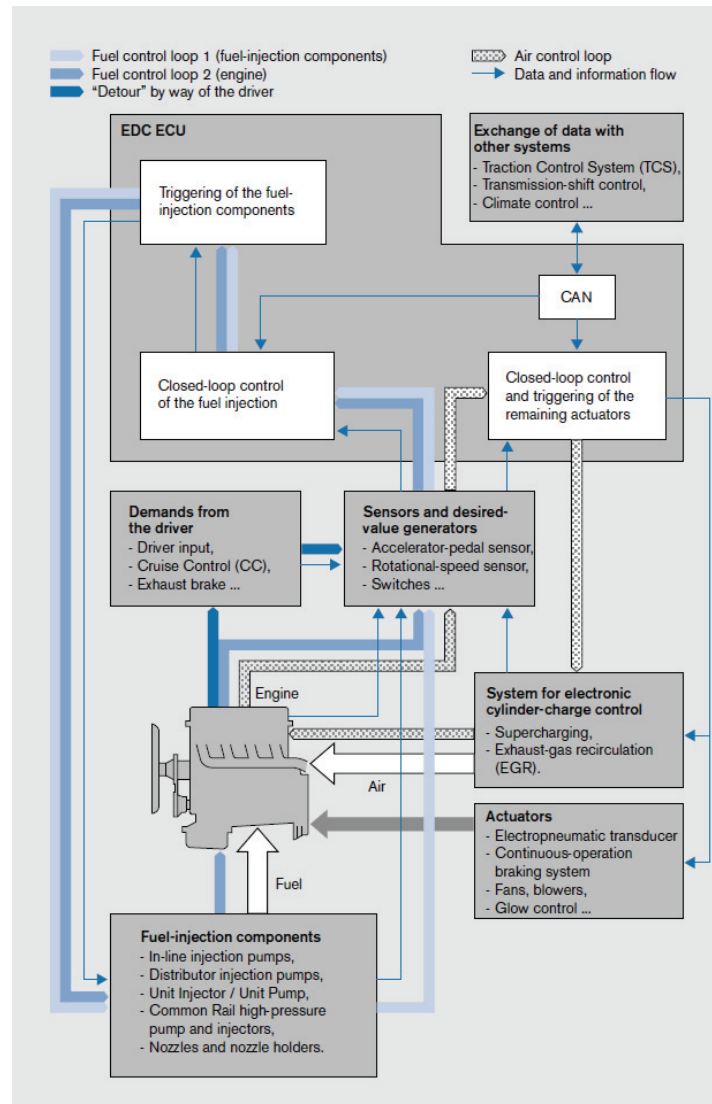
Fig. 8 Block diagram of ECU-Engine Electronics Management

In addition, the measurement areas and the sensors accuracy within their physical resolution can be completely used. The signal conditioning is performed during digital signal processing. Therefore, a signal can be achieved which will be used for calculation of the regulation and control parameters. This signal should be linear and without electromagnetic interference. The physical values obtained from the sensors in computer systems are expressed by using numeric 32 bit system, so that algorithms for control of the process have not a significant impact. Fig. 8 shows the block diagram of basic and control parameters that make close loops for delivery of fuel and air to the engine. Close-loop

control of cylinder charge, on the basis of information on engine working regime and conditions on working media (temperature and pressure), defines boost pressure and level of exhaust gas recirculation (EGR). Main engine fuel control loop (2), on the basis of load and engine speed signals, as well as other working conditions signals, defines cycle fuel injected quantity with the aim to achieve desired engine performances. Additional fuel control loop (1) eliminates cycle-by- cycle and cylinder by cylinder variation of injected fuel quantity enabling to achieve smooth engine running. This loop also helps in the control of exhaust emissions to enable achievement of required limits. Based on previously defined engine functions, the ECU performs electronic control, but not all the functions are used at that time, but only the dominant or necessary one for certain engine working regime. The engine characteristic operating modes are as follows:

- The initial engine starting mode, which takes into account the temperature of the coolant and engine speed; thus, the electronic control unit (ECU) calculates the required amount of injected fuel.
- Normal driving mode, when the quantity of injected fuel depends on the gas pedal position and engine speed. In the calculation of output signal, the characteristic data stored in the ECU EPROM are used, corrected by taking into account other important parameters (coolant temperature, intake air temperature, etc.).
- Idle mode, when control is mandated to maintain a constant speed, which is previously defined and stored in an electronic control unit (ECU). Also, some correction factors are taken into account (degree of engine warm-up, whether other major consumers are involved, etc.). The basic requirements at idling are lower fuel consumption and extremely acceptable exhaust emissions.
- Max. engine speed control ensures that the engine is not mechanically overloaded and thereby damaged. This control is performed by continuous cyclical reduction in the amount of injected fuel when the engine reaches its maximum power. It should be noted that achieving this type of regulation is more difficult if the engine speed at rated power and maximum permissible engine speed lie close to each other.
- Control of desired engine speed between idle and maximum speed is usually characteristic for heavy duty engine and non-road mobile machines. If this feature is turned on, the engine retains almost constant speed regardless of the external resistance, i.e. the need for required power.

The above-listed modes are basic modes, without which it is not possible to effectively use the engine; especially it is not possible with mechanical control. What makes a fundamental difference between electronic and mechanical regulation is that the electronic control can introduce additional features, which contribute to the effectiveness of the engine. Thanks to the electronic management of the electronic control unit it is possible to meet standards for emissions reduction, when regulation exceeds the scope of control and enters into the scope of management. There are some examples of engine managements:

Engine torque management. The purpose of management of engine torque is that torque is dominant characteristic parameter of the vehicle. In electronic systems the position of the accelerator pedal is not viewed as the driver's wish to inject a certain amount of fuel, but to establish the required torque to the driven wheels, enabling movement at the desired speed, which enables overcoming the resistance of the vehicle. The advantage of such management is that without participation of the driver, the ECU determines the amount of fuel injected into the combustion chamber. When calculating the amount of

fuel needed to achieve the desired speed of vehicles, electronic systems must take into account the requirement for power of additional consumer at a vehicle (auxiliary equipments on the vehicle that are powered by engines), and losses that occur in the system of transmission of torque from the wheel through the differential unit to the friction clutch.

Intake air management. In order to achieve optimal combustion in an engine, it is necessary to provide the right mixture of air and fuel. Due to very strict standards on exhaust emissions, modern diesel engines often use exhaust gas recirculation (EGR). The EGR rate is different for various operating modes and this can affect optimal air-fuel ratio. The problem is especially complex since diesel engines very often use turbocharger. Therefore, it is necessary to apply management of intake air to keep optimal air fuel ratio. This type of management can use stored data in memory of ECU that would be used depending on input signals from different sensors or can use a modern approach of calculation using computer models on intake flow, mixture formation and combustion.

Exhaust emission management. Strict emission standard asks for the optimization of all systems and subsystems of the engine, and among the most important is a system of after-treatment of exhaust gases. In this sense, the management of active and passive regeneration of diesel particulate filter is especially important.

5. VERIFICATION OF THE SYSTEM

This section deals with verification of the system results of measurement conducted with the previously explained system.
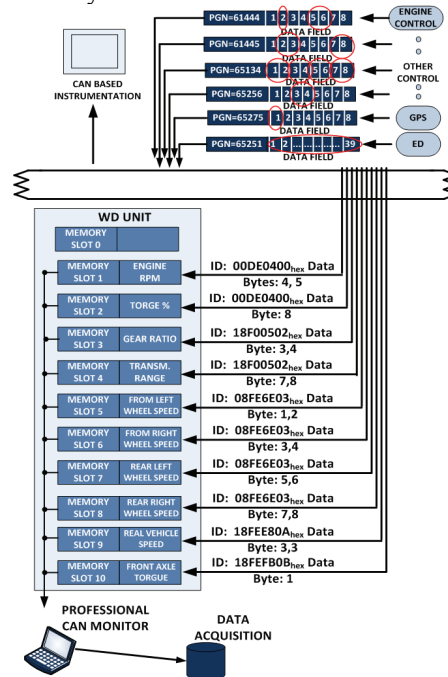

Fig. 9 Measurement concept applied by CAN Bus.

The agricultural tractor with service mass of 2850 kg, mass distribution front: 1250kg, rear: 2600 kg, rated engine power of 66 kW at 2250 rpm with transmission concept 6x2 gear ratio forward, 4 WD and with its own CAN bus is fitted with Watch Dog (WD) hardware, Extension Module (EM) hardware and GPRS modem as given in Fig 6. On the "receiving" side, a server with installed "Professional CAN Terminal" software and receiving GPRS modem is established.

The vehicle is submitted to two types of tests:

- Regular service application (haulage, in field operation, etc.) as per predefined scenario, and,
- Non regular service application, i.e. special tests created for in detail investigation of CAN based acquisition system's capability.

To enable verification of the new data acquisition system the conventional measurement (taken as a reference) of gearbox input torque and rpm is conducted simultaneously with measurement done with the new system. The reference measurement is done by implementation of full bridge strain gauge arrangement for toque measurement (at the output gearbox shaft and propeller shaft for front axle) and inductive transducers for rpm measurement (at the input gearbox shaft) as well as multichannel signals conditioning unit (HBM's Quantum). The position of the transducers installation is selected based on available space for their installation.

The testing according to the first service condition (regular service application) is conducted with the purpose of defining the transmission input torque service load distribution. It is necessary to provide information related to the percentage of particular torque level in total service life of the transmission.

The system is found as capable of enabling accurate measurement with close to no preparation of the tractor. Thanks to the GPRS connection it is possible to make no limitation on area where the tractor will operate as long as the GPRS network is available.

The suggested concept is found to be extremely powerful. Without implementation of the suggested concept (software and hardware developed in this project) the preparation time of the tractor was 2 weeks (because of the complexity of torque measurement in the gearbox). In addition, disassembling of equipment and assembling transmission after measurement regularly took one week. With implementation of CAN based hardware and software for data acquisition the preparation time was a few hours only.

6. CONCLUSION

The CAN based approach in monitoring the vehicles' mechatronics systems can significantly reduce time for vehicle instrumentation and enable development engineers to conduct testing in the already existing vehicle before making the prototype of a new vehicle or system under development.

The concept is accomplished by building up dedicated hardware and software. In total, two hardware and two software components were developed. The results of initial testing of all developed components indicate their good performances.

Accurate monitoring was accomplished through initial testing of the development platform.

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TEORETSKA VERIFIKACIJA PODSISTEMA NA VOZILU POMOĆU CAN BUS I MONITORING ELEKTRONSKE KONTROLNE JEDINICE MOTORA

Umesto mehaničkih sistema nova vozila bivaju opremnjena naprednim mehatroničkim sistemima čiji razvoj i testiranje zahteva novi pristip ispitivanju vozila. Mogućnost korišćenja raspoloživih podataka na vozilu u mreži predstavlja se kao izuzetno moćno sredstvo bržem savlađivanju ciklusa ispitivanja. Ovaj rad se bavi novim pristupom za merenje podataka opterećenja i akvizicije, pomoću čijeg koristanog alata doprinosi se daljem razvoju i testiranju različitih mehatroničkih sistema na vozilu. Novi pristup je baziran na hardverskoj i softverskoj platformi zasnovanoj na glavnim kontrolerima vozila sa zadatkom da omogući relavatne transmisione podatke vezane za eksploataciono opterećenje. Hardver, kao i softverske alatke bi trebale da omoguće kompjuterski monitoring sistema i praćenja vozila pri eksplatacionom radu i ponašanju, kao i da na taj način budu alat za razvoj novih vozila. Novi sistem je testiran u realnom službi. Sistem znatno smanjuje operativno vreme ispitivanja vozila instrumentima i omogućuje precizne podatke akvizicija pri testiranju.

Ključne reči: *vozilo, CAN bus, eksploataciono opterećenje, Monitoring Motora, Elektronska kontrolna jedinica*