ISSN 1330-3651
UDC/UDK 629.33.018:681.5

APPLICATION OF VEHICLE'S CAN BASED NETWORK IN TRANSMISSION SERVICE LOAD DATA ACQUISITION

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Original scientific paper

The implementation of various electronic subsystems in passenger cars and different kinds of on-road and off-road vehicles is constantly expanding. Accordingly the new vehicles, instead of being mechanical systems, become advanced mechatronic systems whose development and testing call for a new approach. Possibility of using data available on vehicles network seems to be extremely powerful tool on it. The paper deals with a new approach for service load data measurement and acquisition as a helpful tool in development and testing of vehicles. Based on complexity of the system and different communication protocols on the vehicles' networks it was found as extremely practical solution to make approach which will be based on standards which are widely accepted by the industry. The new approach is based on hardware and software platform oriented to the main vehicle controllers with the task to acquire data which exist on the network and which are relevant to the transmission service load. The said hardware as well as software utilities have to enable computer based monitoring of the vehicle systems behaviour and in that way to be the tool for new vehicles development. The new system was tested in real service. It was found that the system can enable significantly less time of vehicle instrumentation before testing and accurate data acquisition.

Keywords: *CAN (Controller Area Network), service load, transmission, vehicles*

Primjena mreže vozila temeljene na CAN–u pri skupljanju podataka o radnom opterećenju mjenjača

Izvorni znanstveni članak

Primjena raznih elektroničkih podsustava u putničkim automobilima i različitim vrstama cestovnih i drugih vozila u stalnom je porastu. Stoga nova vozila, umjesto mehaničkih sustava, postaju napredni mehatronički sustavi za čiji je razvoj i ispitivanje potreban novi pristup. Mogućnost korištenja podataka s mreže vozila čini se izvanredno snažnim alatom na njoj. Članak se bavi novim pristupom za mjerenje i dobivanje podataka o radnom opterećenju kao korisnom alatu u razvoju i ispitivanju vozila. Zbog kompleksnosti sustava i različitih komunikacijskih protokola na mrežama vozila smatralo se izvanredno praktičnim rješenjem stvoriti pristup koji će se zasnivati na standardima koji su široko prihvaćeni u industriji. Novi se pristup temelji na platformi hardvera i softvera usmjerenoj glavnim upravljačima vozila sa zadatkom prikupljanja podataka koji postoje na mreži i koji su relevantni za radno opterećenje mjenjača. Mogućnosti spomenutog hardvera kao i softvera trebaju omogućiti upravljanje sustavima vozila temeljeno na računalu i tako biti alat za razvoj novih vozila. Novi je sustav bio testiran u stvarnoj upotrebi. Ustanovilo se da je pomoću sustava potrebno mnogo manje vremena za podešavanje instrumenata vozila prije ispitivanja i dobivanja točnih podataka.

Ključne riječi: *CAN, mjenjač, radno opterećenje, vozila*

1 Introduction

One of the most important factors which impacts a new product development, including its testing, is duration of development activities. It is of great importance to reduce the time from the initial technical specification of the new product till the moment of launching its serial production. That task is mainly oriented to the development engineers who are under great pressure to satisfy market driven demands for fast and reliable new product design.

Taking into consideration mechanical systems like the vehicles, the knowledge of service load is of great importance for development process. The knowledge of service load for particular system under development can:

- Reduce development process dramatically and can make all design calculation extremely accurate. As a consequence, deep understanding of service load, integrated with up-to-date tools for static and dynamic stress calculations including software tools for other phenomena simulation (like vibration, noise, etc.) can make real object testing needless.
- Enable in-lab system testing and verification through exposing it to previously acquired service load. In that way in-field or on-road testing can be avoided and the total testing time can be reduced. It is of importance that in-lab testing, which is based on acquired data which are appropriately evaluated, can be significantly accelerated.

Regularly the new product design follows the route which is given in Fig. 1. From product data specification it comes out that new product will incorporate absolutely new systems as well as systems which already exist in other products. Consequently, in many cases, it can be possible to collect service load data from already existing product i.e. from their service.

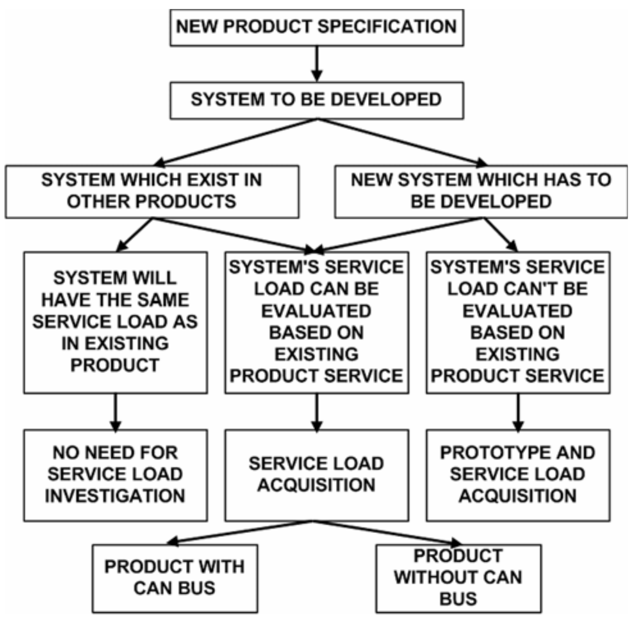

Figure 1 The new product development with reference to the knowledge of the service load

The vehicle transmission units are typical example of a system whose development can be accelerated by including service data from already existing transmissions. The reason is quite obvious.

Many new designed vehicles' transmissions have to be in application as already existing transmissions. The service load of each vehicle transmission depends mainly on vehicle mass, engine power, type of service and type of transmission. The impact to the vehicles' transmission service load also comes from driver behaviour, particular country commercial circumstances, etc. It is obvious that many already existing vehicles of one producer (already in service) can be extremely good base for collecting service load. Simply speaking, if an existing vehicle would be placed in the service conditions which can be expected for the new vehicle then it can be used for service load measurement and acquisition which would be reference input for the new vehicle under development. It is of great importance to analyse the possibility for service data acquiring which would enable faster and more reliable new product development and validation.

2 Conventional and CAN based approach for service data acquisition on the vehicle

Two approaches in transmission service load data acquisition are available with nowadays technology. The first one is oriented to the vehicles without electronic unites especially electronic controllers. To enable service data acquisition on those vehicles the same have to be additionally instrumented with all necessary sensors, signal conditioning units as well as some kind of data logging systems. That process can be very time consuming, expensive and frequently related to the technical problems in transducers installation. In the case when transmission service load has to be investigated the problem of transducers' installation can be extremely difficult based on the fact that measurement has to be done on rotating part in limited space where possibilities for transducer installation and taking signals from them is related to many difficulties. This approach is already evaluated through literature. But, the recent development in vehicle systems brings the new possibilities in the field of measurement. Reality that new vehicles are equipped with dedicated electronic controller units opens possibility for fundamentally new approach in data acquisition.

The said possibility can be studied in Fig. 2 – top where the layout of controllers and other electronic units on up-to-date vehicles is given. The new vehicles are commonly fitted with minimum two to three electronic control units which are oriented to the engine, transmission, etc. Those controllers are interconnected through CAN (Controller Area Network). As a part of driver information system a few terminals are provided as nodes of the CAN. Consequently, the intention for transmission service load investigation has to be oriented toward possibility that many data of interest can be acquired from the vehicle's network rather than to be measured by dedicated and additionally added instrumentation.

3 CAN based system for service load data acquisition

The system which was developed for service load data acquisition on vehicles fitted with CAN bus considers a few hardware items as well as dedicated software. This chapter is related to the concept of the system. Although the system is mainly oriented to the transmission service load acquisition from the CAN bus, it would be clear that its concept enables monitoring of data which are inherent to the all other vehicle's systems.

The concept of the system is based on common situation on nowadays vehicles already fitted with electronic networks which are in use for data interchanging among different vehicle's controllers and their instruments (Fig. 2 - top). In spite of the fact that there are a few protocols which are in use on vehicles' networks it is of importance to be noted that all of them are based, mainly, on the same physical layer which is, nowadays widely accepted by all producers. That is the physical layer defined through ISO 11898 or frequently named as CAN 2.0B. As it is given in Fig. 2 - 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 is clear that data of interest for service load would be placed in Data Field. But, to be in position to use those data a few problems have to be solved. Those problems are mainly related to the CAN identifier (ID).

As it is defined by ISO 11898 CAN ID has to be 29 bits long. But, 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 it has to be analysed in which way SAE J 1939 uses CAN's identifier (Fig. 2). 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 [1]. Actually, all data which have to be sent to the CAN bus are organized in the groups. For example, all data relevant for 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 stated PGN(s) would be: transmission selected gear, transmission actual gear ratio, percent of clutch slip, transmission input shaft speed, etc. It is clear that lots 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.

It is clear that for the concept of service load data acquiring is essential to be familiar with the PGN concept. Unfortunately, the concept of PGN and establishing CAN identifier is not as simple as said 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 recognized that PDU Specific can be defined in two different ways

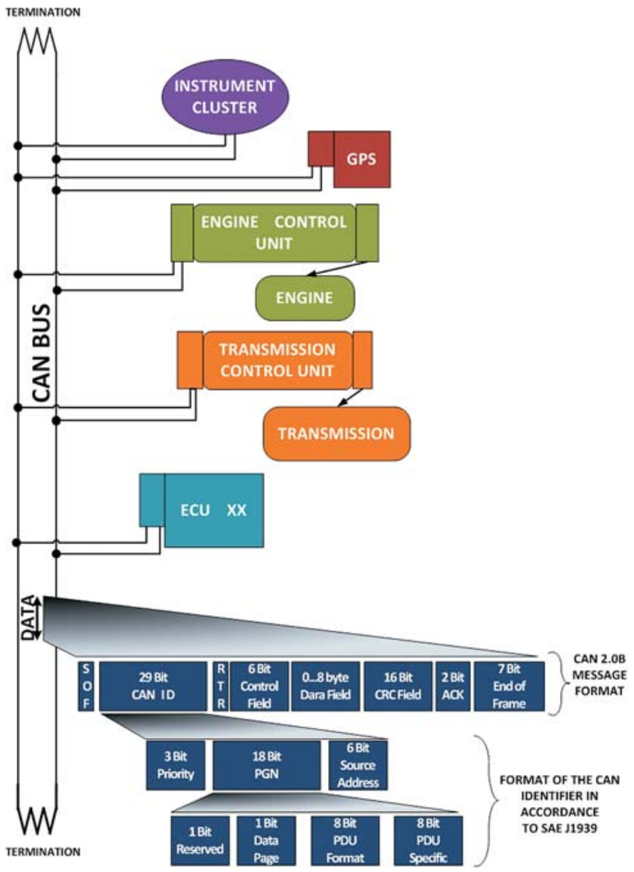

Figure 2 Common configuration of the vehicle's CAN bus (top) and the message format (bottom)

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 approach to the messages on the CAN bus (PDU) very complicated and can cause a lot of problems.

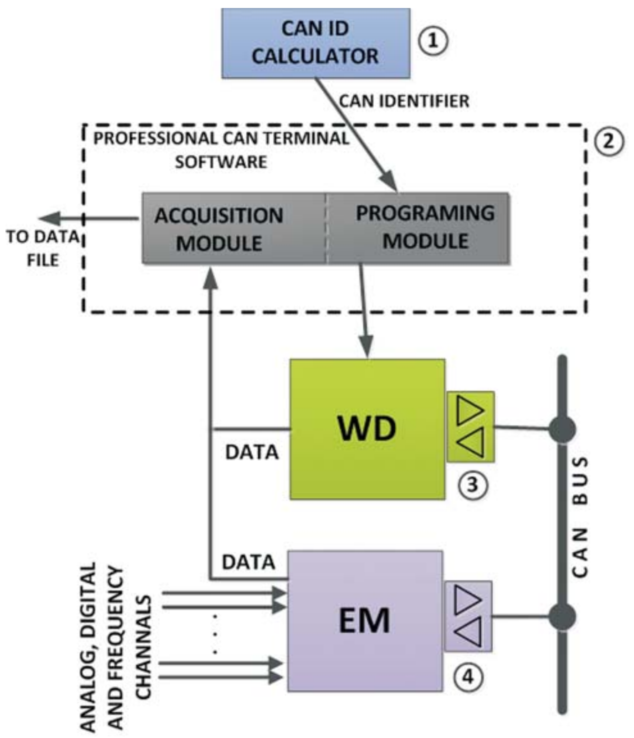

Figure 3 Hardware and software components developed through the project (meaning of numbers and abbreviations are given in the text)

As it was explained, defining the proper PGN is not sufficient for successful data acquisition i.e. acquiring of 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 explained concept of data flow trough CAN bus it is obvious that first interest in establishing the system for data acquisition has to be oriented to providing of adequate software tools for PGN, CAN Identifier (ID) and Data Field evaluation.

To reduce problems i.e. to enable easier service data acquisition trough CAN bus the project whose results are given in this paper considered development of a few 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,
4. Extension Module (EM) – hardware component.

The scheme of functional interdependence of the developed components is given in Fig. 3 where components are marked with appropriate numbers as given above.

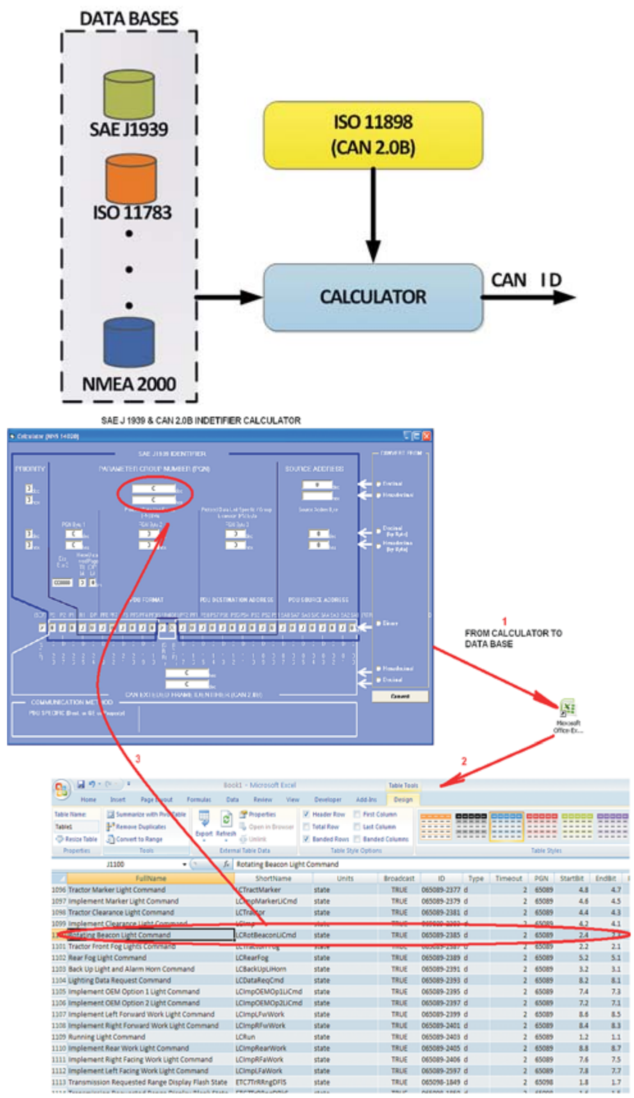

Figure 4 CAN Calculator; top – the software structure; bottom – the monitor page which provides support to the user to calculate CAN ID based on SAE J 1939 protocol

The first of developed components is "CAN identifier (ID) Calculator", with the structure as in Fig. 4. Through various data bases it provides support in defining CAN identifier from different standards including SAE J 1939. The user has to approach the data base through Excel (Fig. 4, path mark with 1). The data base can be searched in different ways including searching based on data of interest such as engine torque, engine rpm, etc. In that way user can find out 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 [2] and other parts of 29 bit identifier (Fig. 4, path mark with 3) in accordance with the previously explained rules. In that way the user is in position to know which message has to be grabbed from the communication on the CAN bus and in position to extract appropriate value(s) from the data field in that message (i.e. from PDU).

Since data are organize in 8 bytes Data Field [1], for successful monitoring it is essential to know the position of the data of interest within Data Field. Last two columns in the data base (see Fig. 4, columns marked with "StartBit" and "EndBit"). In this way the first software component which is developed in this project enables the user to have full support related to the messages on the CAN bus even without his deep knowledge of the protocols.

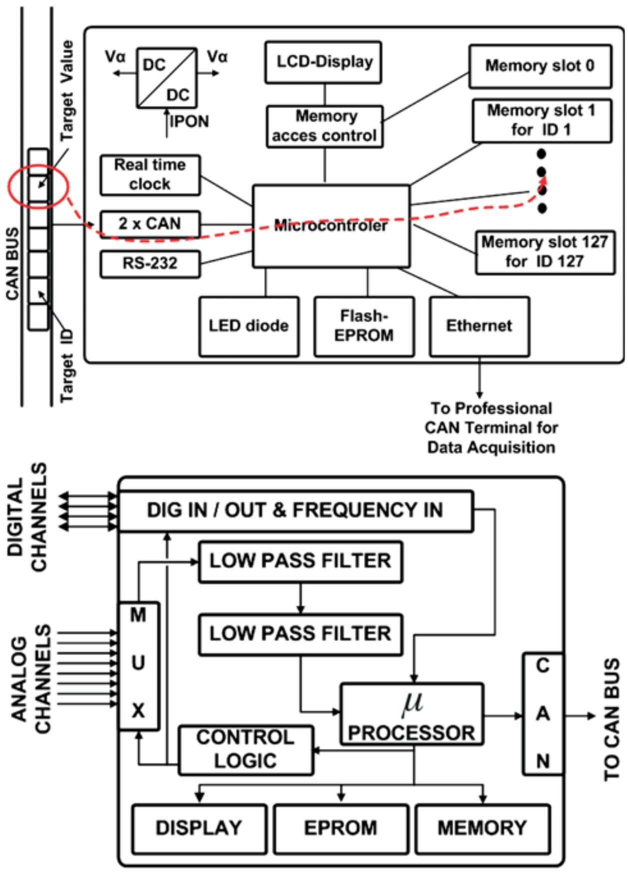

Figure 5 Configuration of the hardware components: top – WD (Watch Dog); bottom- EM (Extension Module)

The next part of the data acquisition system developed for the project is dedicated to hardware (see Fig. 5 – top), named WD. Actually that is 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. 5 – top).

The WD hardware was initially programmed with parameter free software developed in this project. The software drives WD to continuously listen to the traffic on the CAN bus. Once when WD starts its work it asks for values for parameters. Those values have to enable WD to know CAN identifier(s) of interest, part of the data field which has to be extracted from the message with defined identifiers as well as to enable WD to know in which memory slot the extracted value has to be downloaded. This process is visualized with red lines in Fig. 5 (top) and explained with more details and through example related to the transmission related data, later in the text (see Fig. 8 and text in chapter 4).

Once when user defines all parameters WD performs operation of grabbing data of interest from the CAN bus and places values of interest in the 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. 6) has specification as follows:

- Automatic allocation of WD within local network,
- Definition of parameters which define data of interest from CAN bus,
- Monitoring of ongoing communication in real time and data storage,
- Possibility for sending messages to the CAN bus.

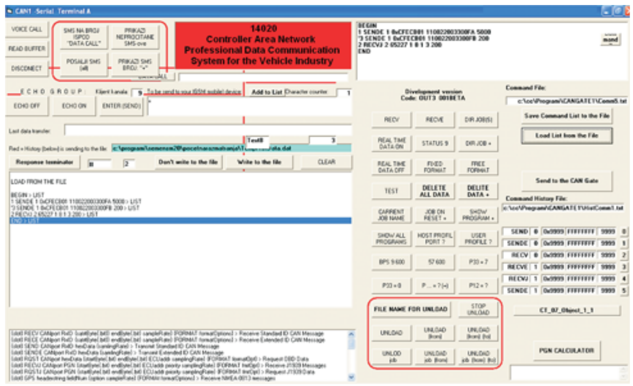

Figure 6 "Professional CAN Terminal" software – the main monitor page

The second hardware component which was developed in this project was "Extension Module" or EM (the configuration given in Fig. 5 – bottom). The EM, among others, performs two essential services:

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

The necessity for development of the module comes from the circumstance that not all values of interest were available on the CAN bus. It is common situation that there are some values of interest for acquisition which are broadcast by not one electronic control unit connected to the vehicle's 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 second noted way has some advantage. It enables utilization of the already existing data acquisition system which is oriented to the CAN bus, for acquisition of all needed data and makes needless any additional measurement and acquisition unit.

In this project the second of the two stated approaches was used.

4 CAN based system application – transmission service load acquisition

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

For the purpose of designing the new agricultural tractor transmission it was necessary to make in detail investigation of gear box input power (actual input rpm and torque) as well as front and rear axle input torque and rpm. All those data were needed as the input for precise design calculation of the new tractor transmission.

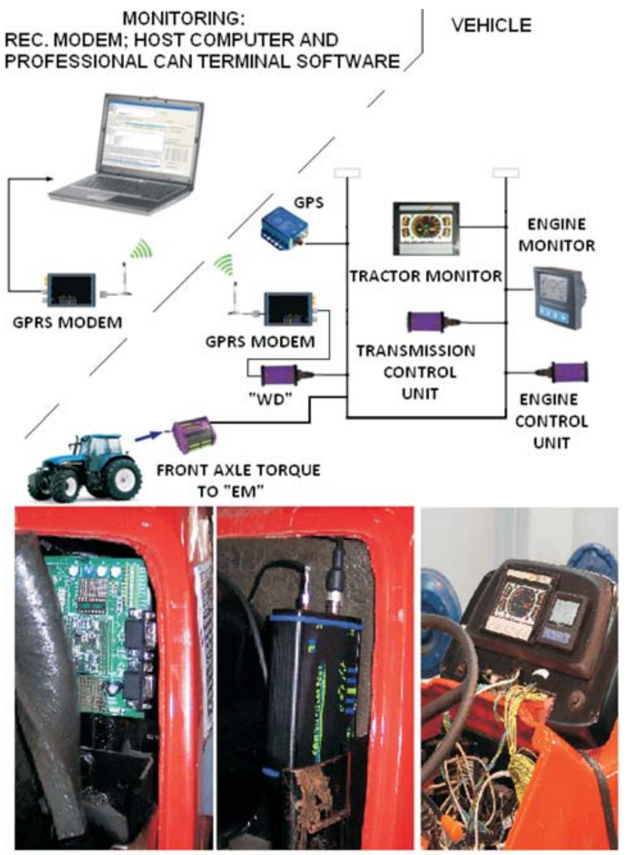

Figure 7 System for service load data acquisition trough CAN bus: top – configuration of the system, bottom left – EM built in the tractor; bottom middle – GPRS modem built in the tractor, bottom left – installation of the WD unit

It was found that the tractor with nearly the same specification as the new tractor which had to be developed existed on the market. As the existing tractor was "CAN based" it was found as cost and time effective to provide transmission service load data by utilization of CAN based data acquisition system on existing tractor. Consequently, it was brought out as 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. 7). For real time data monitoring WD's Ethernet port was connected to Ethernet port of GPRS modem i.e. a data channel was established from CAN bus to GPRS network. Monitoring station was fitted to 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 (broadcast by no one ECU on the network) the Extension Module (ED) was connected to the bus. Since the front axle input torque was not-broadcast value of interest an additional front axle torque measurement line was established on tractor's propeller shaft and the analog signal from the torque conditioning unit was directed to the EM.

Before data acquisition, it was necessary to find out 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 trough 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 4^{th} 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 the corresponding CAN identifier which is of interest as ID = $00DE0400_{hex}$. The whole process can be visualized as it was given in Fig. 8 and represented in a symbolic way as follows:

Engine speed:
Priority Level: 3 >>> ID = $011xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61444_{dec} $00F004_{hex}$ = $xxx001111000000000100xxxxxxxx_{bin}$
Source: 0_{dec} = 0_{hex} = $xxxxxxxxxxxxxxxxxxxxx00000000_{bin}$
Result ID = 217056256_{dec} = $00DE0400_{hex}$
Start position in Data Field: 4^{th} byte
Length: 2 byte

The next value of interest is engine torque or transmission input torque which is broadcast 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, from CAN calculator software it was found that the ID of the message which contains data relevant for torque was 217056256_{dec} or given in-deal:

Engine torque
Priority Level: 3 >>> ID = $011xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 61444_{dec} $00F004_{hex}$ = $xxx001111000000000100xxxxxxxx_{bin}$
Source: 0_{dec} = 0_{hex} = $xxxxxxxxxxxxxxxxxxxxx00000000_{bin}$
Result ID = 217056256_{dec} = $00DE0400_{hex}$
Start position in Data Field: 2^{nd} byte
Length: 1 byte

Even if the torque level is transmitted in percentage of reference engine torque one can easily find out the actual torque. That 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 asked by sending the request with PGN 65251.

Here, we have to recall the part in which the Professional CAN Terminal software was described. As one can recognize in given specification of that software 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 it was given in the software specification, it also has capability to send messages to the CAN bus. Here is clear the purpose of that (sending request with PGN 65251).

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 replay with message with multi-data field (total length 39 bytes) which will be matrix data. Only in that way one will be in position to find out torque value (in N·m). 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 trough request with PGN 65251.

The next values of interest were actual or engaged gear ratio and actual transmission range. Taking together, those 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 = $110xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
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 = $110xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
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, it was needful to provide data for real tractor speed. That is extremely important since there is no other way to find out wheel slip (and to give input to design time for development of differential locks) 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 in accordance with the concept as given bellow. The priority and position of the data in data field are:

Navigation-Based Vehicle Speed (real tractor speed):
Priority Level: 6
ID=$110xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN:65256_{dec}= $00FEE8_{hex}$=$xxx001111111011101000xxxxxxxx_{bin}$
Source: 10_{dec} A_{hex}= $xxxxxxxxxxxxxxxxxxxxx00001010_{bin}$
Result ID = 419358730_{dec} = $18FEE80A_{hex}$
Start position in Data Field: 3rd byte
Length: 2 byte

Special interest in new transmission development was given to the ratio of slip between left and right wheels on the same axle. For that purpose in addition to measurement of real tractor speed, it was necessary to provide data related to the wheels speed. It was demonstrated that even those values can be measured without installation of additional transducers i.e. from the CAN bus. Those pieces of information are available from torque distributor or ASR controller or/and ABS controller. Tractor which was under the test was fitted with torque distributor controller which was also used as differential lock controller. It was found that controller follows SAE J 1939 protocol. Consequently, all needed data were located in the messages with PDU 65134. Through CAN calculator it was found:

Actual wheel speed (High resolution wheel speed)
Priority Leve: 2 >>> ID = $010xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN: 65134_{dec} $00FE6E_{hex}$=$xxx001111111001101110xxxxxxxx_{bin}$
Source: 3_{dec} =1_{hex}= $xxxxxxxxxxxxxxxxxxxxx00000011_{bin}$
Result ID = 150892035_{dec} = $08FE6E03_{hex}$
Start position in Data Field –Front left wheel: 1th byte
Length: 2 byte
Start position in Data Field –Front right wheel: 3th byte
Length: 2 byte
Start position in Data Field –rear left wheel: 5th byte
Length: 2 byte
Start position in Data Field –rear right wheel: 7th byte
Length: 2 byte

Till now the paper discussed possibilities of measurement and data acquisition of the transmission service load without any additional instrumentation out of controllers which already exists on the vehicle under the test. But, it can happen that some values of interest are not available on vehicle's CAN bus. In such cases it is necessary to install appropriate measurement system for that (those) value(s). As per nowadays technology all signals for additionally measured values have to be directed from analog to digital converters and after that transferred to the files. That situation opens the problem of time base synchronization. In practice, system which collects data from CAN bus has its oven time base and time stamping of data acquired from CAN bus takes this time base as the reference. All other signals which come from additionally installed measurement equipment have their oven time base. In cases when all measured data have to be analyzed with the same time base that can open the problem.

To avoid problem of time synchronization of acquired data it was decided to make an extension of existing CAN on the tractor. That was done by implementation of previously explained EM. Basically speaking the system had a function to transfer analog measured values to the CAN messages and to broadcast the same on existing tractor's CAN bus. In that way the WD was in position to acquire the missing (front axle torque) data from CAN bus in the same way as all other values and all of them would be acquired with the same time reference.

The extension considers ED i.e. additional CAN based equipment with A/D converter, its own controller and built in software for assembling SAE J 1939 messages. As it is given at the end of previous Chapter and in Fig. 5 – bottom, the hardware was designed as 8 channels analog input module with CAN controller.

Since SAE J 1939 does not have predefined PGN for front axle torque it was decided to transmit front axle torque with the PGN which is referent for retarder fluid pressure. That does not ruin generality of the approach since the agricultural tractors are without retarders (i.e. the PGN for retarder values were unused).

The front axle torque was transmitted with designation as follows:

Front axle torque (Retarder fluid pressure PGN used)
Priority Level: 6 >>> ID = $110xxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}$
PGN:65275_{dec}=$18FEFB0B_{hex}$
Source: 11_{dec} B_{hex}= $xxxxxxxxxxxxxxxxxxxxx00001011_{bin}$
Result ID= 419363595_{dec} = $18FEFB0B_{hex}$
Start position in Data Field: 1st byte
Length: 1 byte

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5 Verification of the system and results

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

The agricultural tractor with service mass of 2 850 kg, mass distribution front: 1 250 kg, rear: 2 600 kg, rated engine power of 66 kW at 2250 rpm with transmission concept 6×2 gear ratio forward, 4 WD and with its own CAN bus was fitted with Watch Dog (WD) hardware, Extension Module (EM) hardware and GPRS modem as given in Fig. 7. On the "receiving" side server was established with installed "Professional CAN Terminal" software and receiving GPRS modem.

The tractor was 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 was conducted simultaneously with measurement done with the new system. The reference measurement was done by implementation of full bridge strain gauge arrangement for torque 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 multi channel signals conditioning unit (HBM's Quantum). The position of the transducers installation was selected based on available space for their installation.

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

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

It was found that the suggested concept is 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 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.

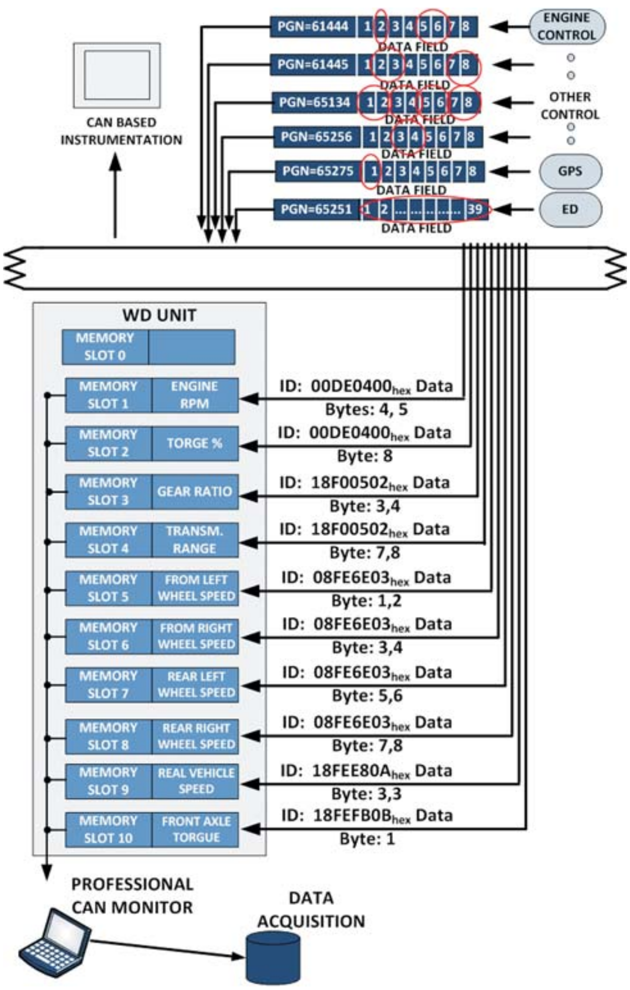

Figure 8 Concept of the measurement

The concept of that measurement was given in Fig. 8 and explained bellow.

The memory slot 1 of the WD hardware was programmed (with Professional CAN Terminal software) to acquire all messages with ID $00DE0400_{hex}$, to extract the 4th and 5th byte of the date field and to transfer the same to the server as value of transmission input rpm. Memory slot 2 was programmed to grab the messages with the same identifier but to extract the 8th byte and to transfer them as the value of transmission input torque.

Memory slot 3 was for grabbing the 3rd and 4th byte of the messages with ID $18F00502_{hex}$ i.e. actual gear ratio while the memory slot 4 was oriented to the 7th and 8th byte of messages with the same ID i.e. toward data related to the selected transmission range.

Memory slots 5 to 8 were programmed for wheel speed data (ID 08FE6E03$_{hex}$). Last two memory slots were programmed for real vehicle speed data and front axle torque data with ID(s) as it was given in Fig. 8.

The results of data acquisition (conducted in regular service conditions) are given in Fig. 9. Simultaneous acquiring of torque and rpm values enabled direct matrix presentation of power/rpm. It is of importance to be recognized that both values are acquired from the CAN message with the same identifier. Since there was no time difference in their acquiring the same can be easily compared with values acquired through reference measurement system. For easier comparison the acquired data are normalized i.e. divided by rated value. More precisely: from acquired values of rpm and torque was calculated input power level and that value was normalized (see ordinate in Fig. 9). Also, the acquired value for rpm was normalized (taking as the reference rated rpm) and that normalized value was placed on the abscissa. The figures in the counter graph (Fig. 9) represent the same percentage levels.

As it was given above, the reference system was HBM Quantum unit. That unit is multi channel data conditioner with simultaneous sampling on all channels. In that way it can be taken as convenient for verification of data collected through CAN bus. The next advantage of using Quantum unit for reference is its capability to monitor CAN bus. In that way it was possible to establish absolutely correct and accurate comparison of the measured values without any time lag.

No significant difference in rpm values was found for the periods when transmission was loaded i.e. while the clutch was engaged. For the whole band of engine rpm: 700 to 2 250 rpm the absolute difference between rpm value provided through CAN bus and reference value was less than 1,6 rpm. The difference was in the range of –0,6 to 1 rpm.

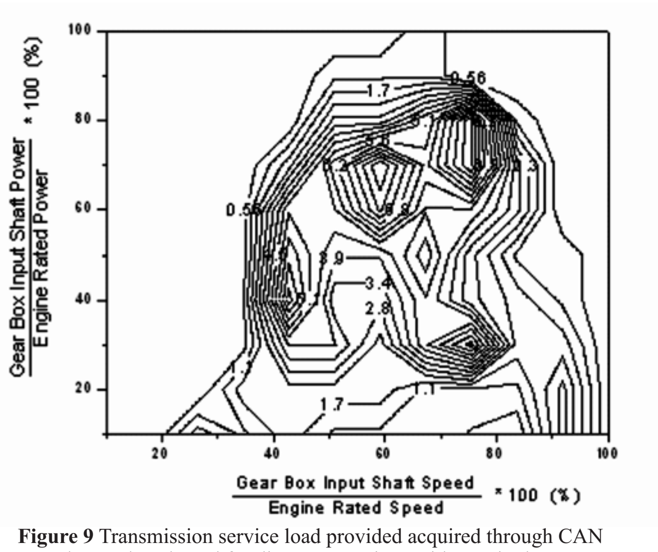

Figure 9 Transmission service load provided acquired through CAN bus and evaluated for direct comparison with matrix data related to PGN 65251

Fig. 10 top shows the difference in rpm. For the analysis purpose all samples for referent rpm were divided in 50 rpm range bins. Each reference rpm sample was compared with its corresponding value taken from CAN bus "simultaneously". The difference which was calculated for each band of 50 rpm was given in Fig. 10, top. As it can be found the difference is at a very low level but higher than 0,125 rpm what is the resolution for rpm value specified in SAE J 1939. There are two reasons for that. The first one is, out of question, the accuracy of measurement. The second reason for difference is that the samples were not taken simultaneously. Actually, it was found extremely difficult to take samples of referent signal simultaneously with signal from the CAN bus since the engine control unit broadcast messages with PGN 61444 with frequency which is not uniform (depends on engine rpm). Anyhow, the difference which was found in rpm is less than 0,15 % of idle engine speed. Consequently, it is obvious that the difference found in engine rpm is negligible.

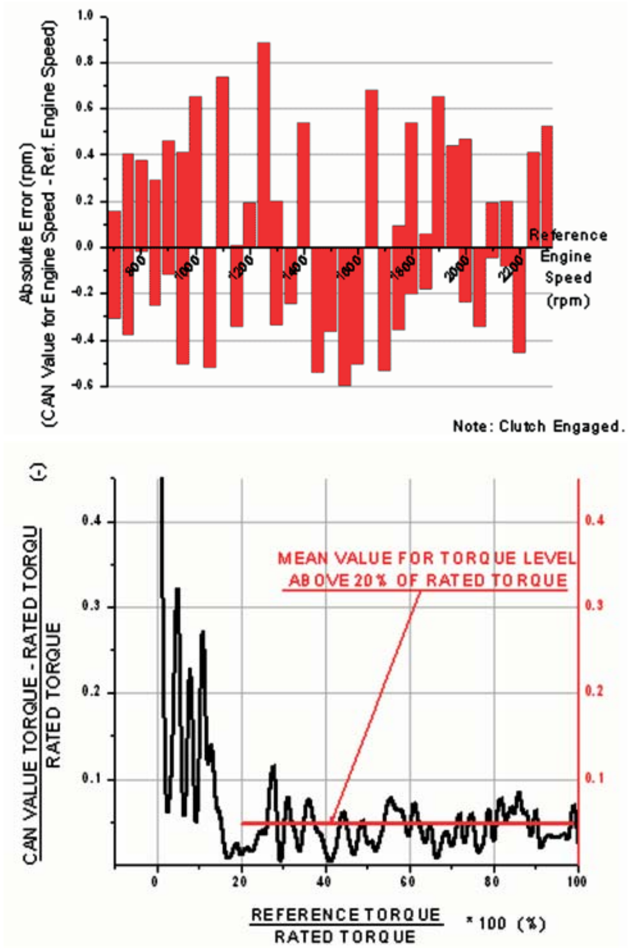

Figure 10 Analyses of the difference between CAN value for engine speed and reference engine speed (top) and CAN value torque and reference torque (bottom)

The torque signal acquired through CAN bus was found with significant difference to the reference signal. The difference is given in Fig. 10, bottom. It is obvious that for values above 20 % of nominal (rated) engine torque the difference between referent torque value and torque value provided through CAN based system was up to 10 % of the nominal torque.

Here one has to bring back the method of measurement. The torque value which was taken as reference was measured at the gearbox output (there was no space for transducer installation at the gearbox input). It was expected that the reference value would be less than the torque value which was provided through the CAN bus and which is related to the engine torque output (which is equal to transmission torque input) based on the fact that the losses in transmission must be taken in consideration.

The tested tractor's gear box was designed with one constant-mash gear pair and another pair of gear which defines the actual gear ratio (final reduction at the transmission output was not used during the test). For one pair of spur type gears (as in the transmission under the test) the expected efficiency is in the range of 0,99 to 0,95. Consequently, for the two pairs one can expect efficiency of 0,98 to 0,9. That absolutely matches the difference in torque signals found during the testing in periods when torque was above 20 % of nominal engine torque. For the lower value of transmission torque (below level of 20 % of nominal torque) the difference is much higher and with large variation. But, those low values of torque come mainly from the transient periods of clutch engagement and periods of clutch disengagement.

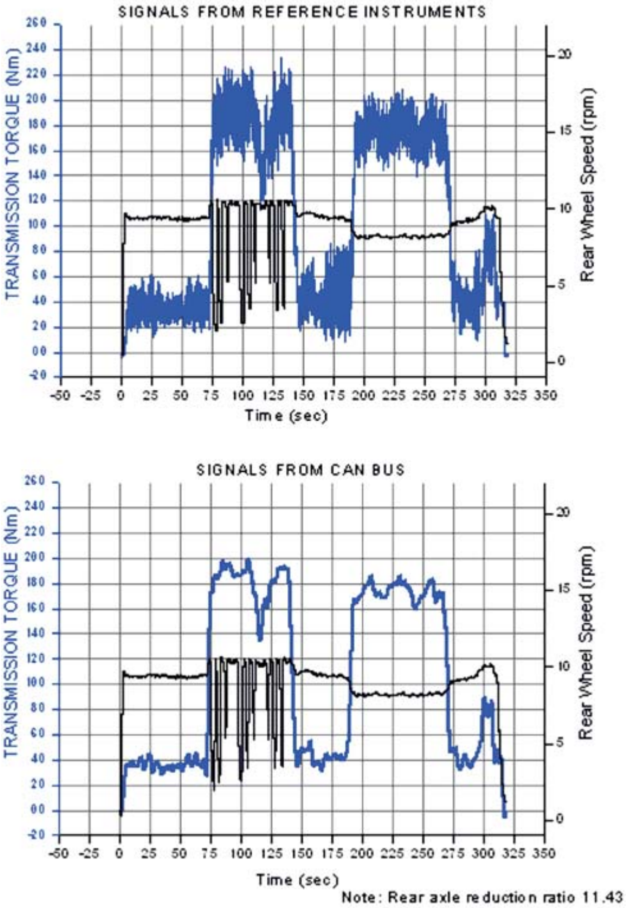

Figure 11 Comparison between data provided through reference instruments (top) and CAN bus (bottom) for transmission torque and rear wheel rpm. Conditions: bare tractor, constant speed.

It is of main importance that for torque values which are of importance for identification of transmission service load (and those are obviously not very low values) the system has shown reasonable level of accuracy.

The system testing was, also, oriented to the EM verification. Based on existence of reference signals for transmission output torque (which is equal to rear axle torque) it was found as useful to make a test in which EM will acquire the signal from the same transducer which was monitored by HBM Quantum and to send the data to the CAN bus. After the few specific tests (defined as "non regular service application") the analysis was done. The results of the analysis are given in Fig. 11 and Fig. 12.

Fig. 11 and Fig. 12 – top show actual value of the rear axle torque acquired by referent system. In the bottom of the same figures are given the results of the particular test provided through EM and WD module. It is obvious that there is no significant difference in rpm values. Through comparison of torque signals one can find difference in signal character. That comes from the presence of the low pass filter on the Extension Module.

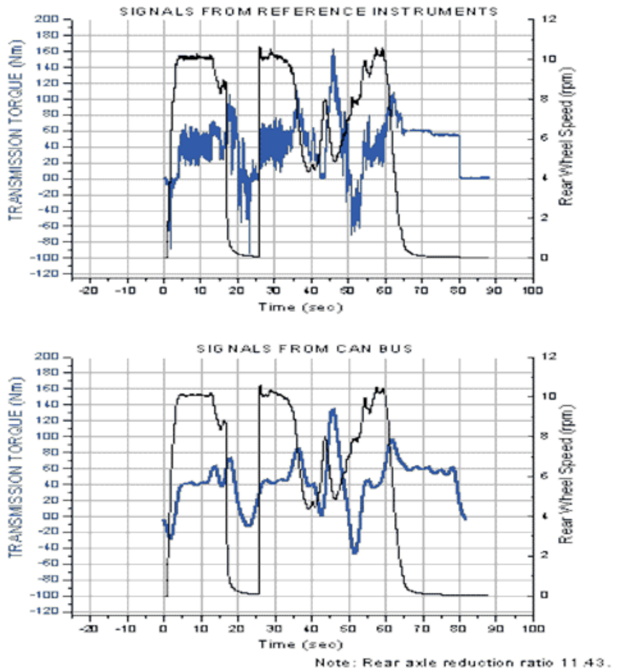

Figure 12 Comparison between data provided through reference instruments (top) and CAN bus (bottom) for transmission torque and rear wheel rpm. Conditions: Bare tractor, acceleration and deceleration.

It is obvious that the signals provided through Extension Module (EM) are actually the same as those provided through the referent system but without higher frequency components. Consequently, the EM was found as good in the service, with performances which enable accurate data acquisition and their transfer to the CAN bus, but with limitation in frequency response which is related to the input filter specification.

6 Conclusion

The process of service load data acquisition on vehicles has passed through significant changes which are caused by dramatic improvement in the vehicles' technology. Instead of being oriented to the dedicated measurement systems which are added to vehicle for measurement purpose only, up-to-date acquisition systems have to be oriented to the vehicles' networks, where service load data already exist. That creates demand for the appropriate – the new platform which will be used for testing and verification of the vehicles. The new platform has to be network oriented data acquisition systems. The paper proposes the advanced measurement and data acquisition system of that kind.

It was shown that CAN based approach in investigation of service load can significantly reduce time for vehicle instrumentation and enable development engineer to make the whole testing in the already existing vehicle before making the prototype of the new vehicle or system under development.

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

Through initial testing of the development platform accurate measurement of agricultural tractor's transmission service load was accomplished in real service conditions. Since the developed concept was not limited to transmission and agricultural tractors, only, it comes out that the chosen approach is generally applicable to different systems on up to date vehicles which consider local networks.

7 References

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