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# New control system concept for the tank transmission with two planetary gearboxes

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**A new concept of transmission control system for high-speed tracked vehicles with two planetary gearboxes has been realized and named GC TRONIC. It is based on the use of electrohydraulic parts, with the microcontroller as an electronic control device. The sistem provides an automatic and controlled gear change process under load, without using the main clutch*) except for starting the vehicle. This paper gives the basic information about this system and reviews the gear change output characteristics achieved on the test stand with real transmission.**

*Key words:* **tracked vehicle, transmission, automatization, microcontroller, GC TRONIC system.**

## Introduction

THE tracked vehicle transmission is a complex power train with integrated functions of rectilinear motion, turning, and braking of the vehicle.

The transmission with two final planetary gearboxes is a mechanical transmission concept, which is present in a number of tracked vehicles, first of all in those from Eastern Europe. Gear change during rectilinear motion in this transmission is achieved with the help of mechanical control commands and hydraulic executive units, engaging multiple friction clutches in gearboxes.

The development of electronics, especially microprocessors, enabled the transmission automatization in order to achieve better vehicle performances and remove disadvantages resulting from existing control system.

The gear change under load and continuous power flow researches [1] were the foundation for development of a completely new control system concept for the transmission with final gearboxes. It is based on the use of electronics and electrohydraulic units. Solutions of some components, applied in the system design, provide better vehicle performances and eliminate disadvantages of standard system. The expression "transmission control" in this paper means the gear change process control during the vehicle rectilinear motion.

The essence of this system (named GC TRONIC) functioning is contained in an original solution of gear ratio change process control, i.e. the gearbox friction unit control, with the help of specially designed pressure modulation devices. By using these devices and other electrohydraulic system components, as well as the microcontroller, necessary control laws and a satisfying transitional response synchronization in both gearboxes are obtained. This paper describes a general system configuration and the output characteristics of gear change, accomplished on the test stand with the real transmission.

## Standard control system concept

The tracked vehicle transmission with two planetary gearboxes is a mechanical transmission concept, shown in Fig.1. In its gearboxes there are integrated functions of rectilinear motion, turning, and braking of the vehicle. They are achieved by activaing appropriate friction clutches in gearboxes, with the help of hydraulic control system.

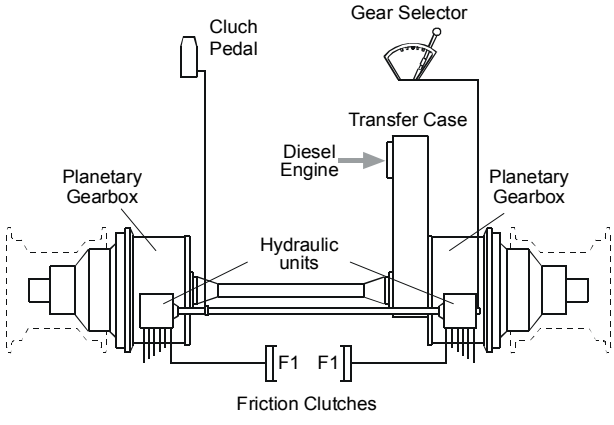


**Figure 1.** Standard control system concept

The standard solution of the transmission control with two planetary gearboxes, Fig.1, consists of mechanical commands (main clutch and gear selector) and hydraulic executive units, i.e. hydraulic valves, placed on the gearboxes. Other system components are not shown. The gear change in transmission with this control system is achieved by the power flow interruption, using the main

*) Under the main clutch command in the transmission with two planetary gearboxes we mean command which disengages friction clutches from oil pressure, and in that way achieves power flow interruption in transmission.

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clutch mechanically connected to hydraulic units. It is a classical main clutch referring to its function rather then to its design. That is because the power flow interruption is achieved by unloading the oil pressure in friction units. By putting the gear selector lever, i.e. hydraulic units, in desired position, oil flow in corresponding gearbox friction units and the engagement of the desired gear are provided.

Hydraulic units represent complex components which contain the vehicle turning functions. The gear change duration and specifications of the transient response are determined by duration and intensity of the main clutch command engagement. This kind of gear change has its disadvantages resulting from the way of its realization. With this vehicle type, every power flow interruption during the gear change leads to an unwanted vehicle speed decrease, higher dynamic loads in the system of propulsion and transmission, increased fuel consumption, and increased strain of the driver.

With the tracked vehicles of the type, demands for improved performance cannot be achieved without partial or complete elimination of disadvantages. That is a constant task for a constructor. This paper shows the way of solving these problems.

## New control system concept

The new control system concept for the transmission with two planetary gearboxes, named GC TRONIC, is based on the use of electrohydraulic components and the electronic control by the microcontroller [2]. The system provides high-level automatization of gear change process in order to accomplish the following objectives:

- ease of transmission-vehicle control,
- improved vehicle performance due to the gear change achieved under load and without power flow interruption,
- decrease of dynamic and thermal loads in the transmission,
- reduction of fuel consumption,
- decrease of gear change control time.

The disposition of the GC TRONIC system main components participating in the gear change process is shown in Figure 2 [3]. The system consists of:

- electromechanical components, i.e. control commands, e.g. gear selector, clutch pedal, and accelerator pedal,
- electrohydraulic components or electrohydraulic units,
- ETCU (Electronic Transmission Control Unit) - an electronic device, i.e. the transmission controller as an essential system component.

The gear selector is an electromechanical assembly of a modern construction having two levers: the first lever is used for choosing direction and the second lever is used for gear change. The gear selector and other components of the system are connected by cable. Electrical signals about the position of selector levers, accelerator pedal and other sensors are introduced into the transmission controller and used for control.

The clutch pedal is connected with electrohydraulic units by a leverage. It has two functions:

- to achieve the power flow interruption during the manual gear ratio change,
- to start the vehicle in operating modes of semiautomatic or fully automatic gear change.

Electrohydraulic units are complex hydraulic components with solenoid values, containing the pressure regulator, hydraulic valves, pressure modulation devices, oil filters, and position sensors of hydraulic executive components. These units are mainly intended for the gear change realization and provide necessary laws for the engagement of gearbox friction clutches.

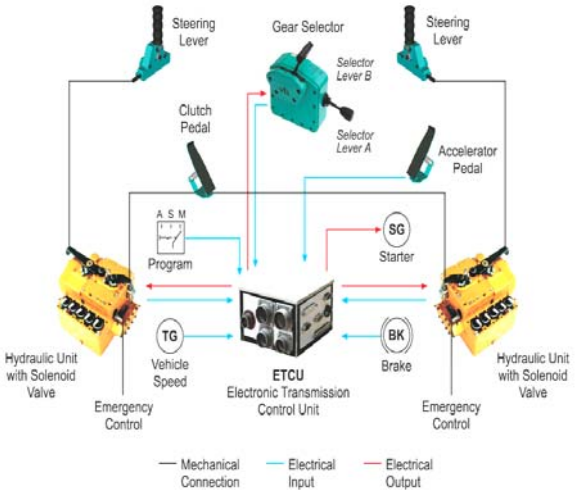


**Figure 2.** New control system concept

The electronic device is a microprocessor system, i.e. ETCU. It receives electrical signals from command devices and system sensors, processes them, and transforms them into output signals for solenoid valves of electrohydraulic units. The transmission controller contains a few modules, e.g.: a main board with the processor, flash disc and RAM memory, different interfaces, integrated LAN and graphical cards; a DC-DC voltage converter; analog and digital cards with appropriate capacity. The electronic device hardware is realized according to the PC 104 standard. Its software is developed on PC and is appropriate for new system demands.

The GC TRONIC control system can work in three operating modes, depending on chosen program: the manual mode, the semiautomatic mode, and the fully automatic mode. The manual mode means that the gear change is obtained using the main clutch, but with certain improvements in relation to standard system.

The semiautomatic mode is characterized by the gear change under load, without using the main clutch. The gear selection is left to the driver who simply uses the selector lever. The whole gear change process is performed automatically with controlled engagement and disengagement of friction units.

The same transient process characterizes the fully automatic mode as at the semiautomatic gear change but it is achieved without the driver's influence on gear selection. This option demands additional sensors in the system (a position sensor of the accelerator pedal and a speed vehicle sensor), more complex software and represents more expensive solution. Therefore, the semiautomatic mode of gear change is quite acceptable.

## Operating of the *GC TRONIC* system

The operation of the GC TRONIC system during the gear change is based on the original solution of electrohydraulic and electronic components providing:

- continuous power flow during the gear change under load [4],

- controlled friction units engagement in gearboxes due to the obtained pressure modulation,
- all gear control using one pressure modulation device [5] in each gearbox,
- desired law of pressure transient process [6] in all gear changes.

These system possibilities are the result of original solution of the pressure modulation device design, which consists of special hydraulic components and solenoid valves.

The principle scheme of the gear change control using the GC TRONIC system is presented in Fig.3.

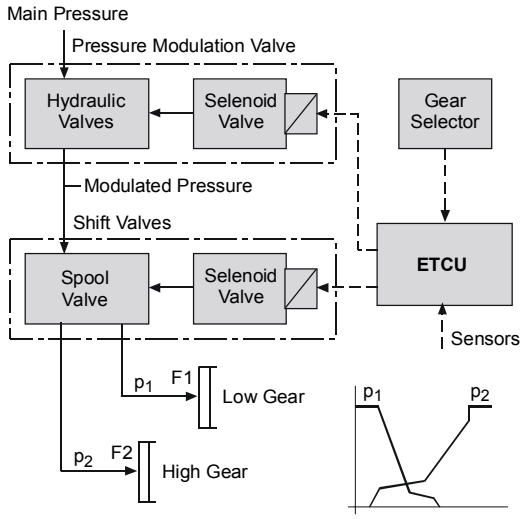


**Figure 3.** Operating of the GC TRONIC system

Electrical signals of a chosen gear from the selector and other sensors are introduced into ETCU which processes them and forms control signals. ETCU sends the first group of electrical signals to the block of solenoid valves which control spool valves of the gear change, and the other group to the solenoid valves of the pressure modulation device. Based on that signal and the pressure modulation device, a hydraulic signal, i.e. the modulated pressure of certain character for engagement of friction clutches, is formed.

The desired law of friction clutches control is achieved by selecting construction parameters of hydraulic components of the pressure modulation device, combined with the parameters of the software controlling the solenoid valve of this device. In each electrohydraulic device there is a pressure modulation device which serves for all gear ratios in a gearbox.

## Testing of the *GC TRONIC* system

The new transmission control system concept with two planetary gearboxes is successfully tested under laboratory conditions on the test stand (Fig.4) with the real transmission. These testings were preceded by testings of each electrohydraulic device, outside and inside the gearbox, because of necessary adjustments, the achievement of necessary functions and dynamic testings. In addition, hardware and software of the electronic device were tested in order to establish all input and output signals according to the defined algorithm. During the testings, with the help of the data acquisition device, we registered many testing parameters, i.e. pressures of friction clutches in both gearboxes, and some control electrical signals. Control panel on the screen of monitor performs supervision of the system operation and tracks the performance of components.

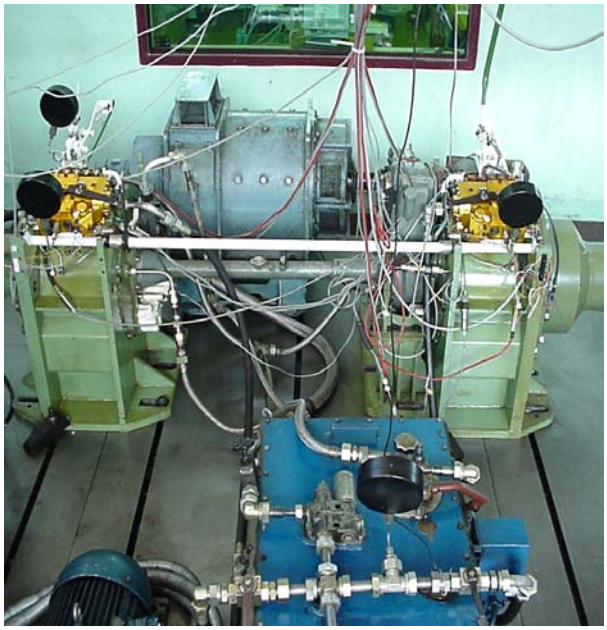

**Figure 4.** Test stand for measurements

The whole testing of the GC TRONIC system is realized in a few phases of the component testings and the whole system testings. The most important testings are:

- previous testings,
- functional testings,
- dynamic testings and
- gear change process testings.

*Previous testings* included various testings of Electrohydraulic Valve Bodies (EHVB) and their components, e.g.:

- testing of oil filter flow characteristics,
- testing of solenoid valve temperature and current load during long work,
- testing of microswitch reliability.

*Functional testings* were realized in order to check functional characteristics of EHVB in assembly and outside the gearbox. They included:

- establishing functions of pressure regulator, main clutch command, steering commands and pressure amplifiers,
- checking of oil distribution to friction clutches,
- measuring of inside oil losses in EHVB assemblies at every gear ratio,
- measuring the response time of the pistons of EHVB distribution valves in relation to electrical control signals, and
- start check of pressure modulation device function, etc.

*Dynamic testings* were achieved after successful functional testings in order to check the EHVB reliability in conditions of frequent gear changes. Lasting for hours, EHVB testings were performed by measuring characteristic parameters during several different time intervals. In that way several thousand of gear changes and working condition changes of EHBV parts were achieved. After that, EHVB were submitted to an accelerated testing for hours, which consisted of their continuous work in gearboxes on the test stand.

After these testings, complex testings of gear change process were started in order to achieve optimal transmission control laws characterized by:

- gear change under load and without power flow interruption,
- minimal time duration of the transient process,
- continuous engagement of friction clutches,

- uniform load of the propulsion motor,
- minimum vehicle speed deceleration during the transient process,
- low dynamic load of the system of propulsion and transmission, and
- minimal thermal loads of friction clutches.

Diagrams illustrating gear change processes with the GC TRONIC system are shown in Fig.5.

Measurement values which characterize every transient process, i.e. pressures of appropriate friction clutches of planetary gearboxes are presented on diagrams. The desired character of friction clutches engagement can be achieved

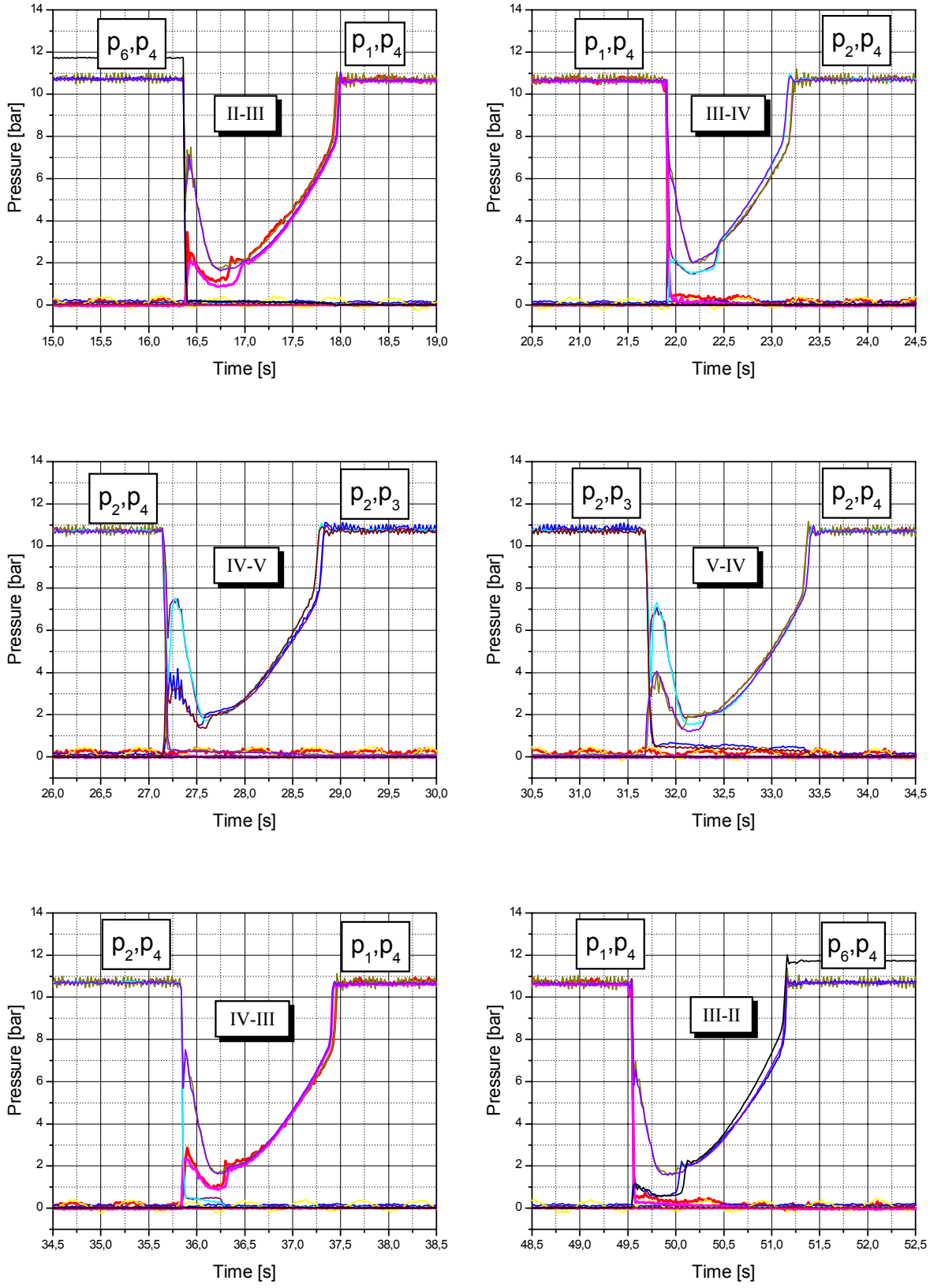


**Figure 5.** Measurement values registered during the gear change with the GC TRONIC system

by selecting modulation device design parameters and control program parameters.

## Performances of the GC TRONIC system

Diagrams of the gear change process (IV-V and V-IV), achieved with different parameters of pressure modulation device and control software, are presented in Fig.6 and 7 in order to show wide possibilities of the GC tronic system.

The influence of the throttle diameter, D4 [3], on the change of pressure in gearbox friction clutches is shown in Fig.6. This parameter of the pressure modulation device has great influence on the intensity of pressure increase during the engagement of friction clutches. In this way, it influen

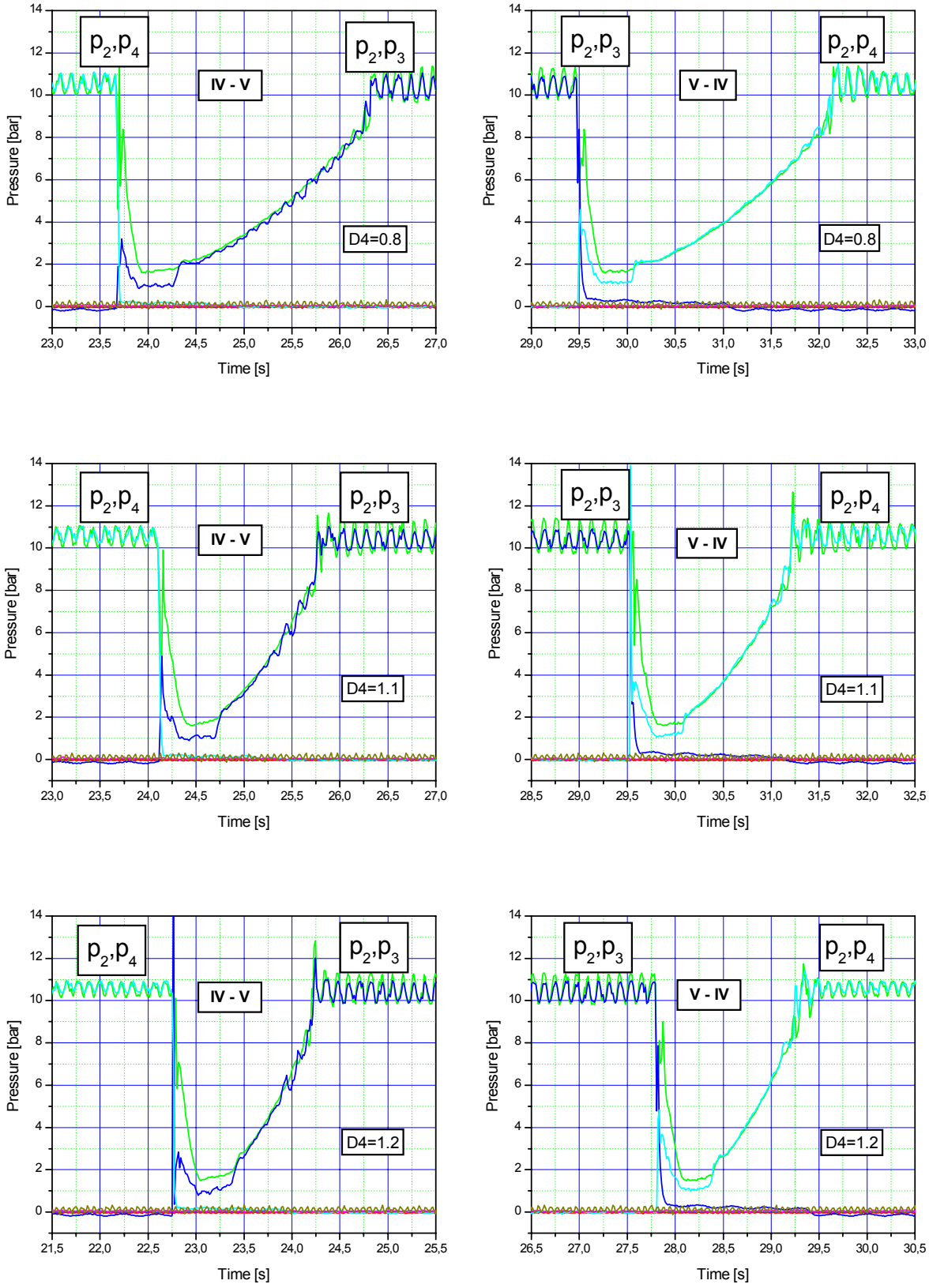


**Figure 6.** Change of pressure in gearbox friction clutches with different parameters of pressure modulation devices

ces on the transient response duration. The pressure values in friction clutches of both gearboxes, during the transient response, show an exceptional coincidence indicating the full synchronization of their engagement.

The influence of the software parameter T2, which controls the pressure modulation device during the gear ratio change, on the transient response is shown in Fig.7. This parameter value has a great influence on the transient response duration, and especially on the beginning of pressure modulation. The lower value of T2 is, the lower interrupt of power flow is. The low-pressure nonsynchronization in gearbox friction clutches is shown when parameter T2 has lower value. This is the result of different production quality of the most important EHVB parts in this phase of

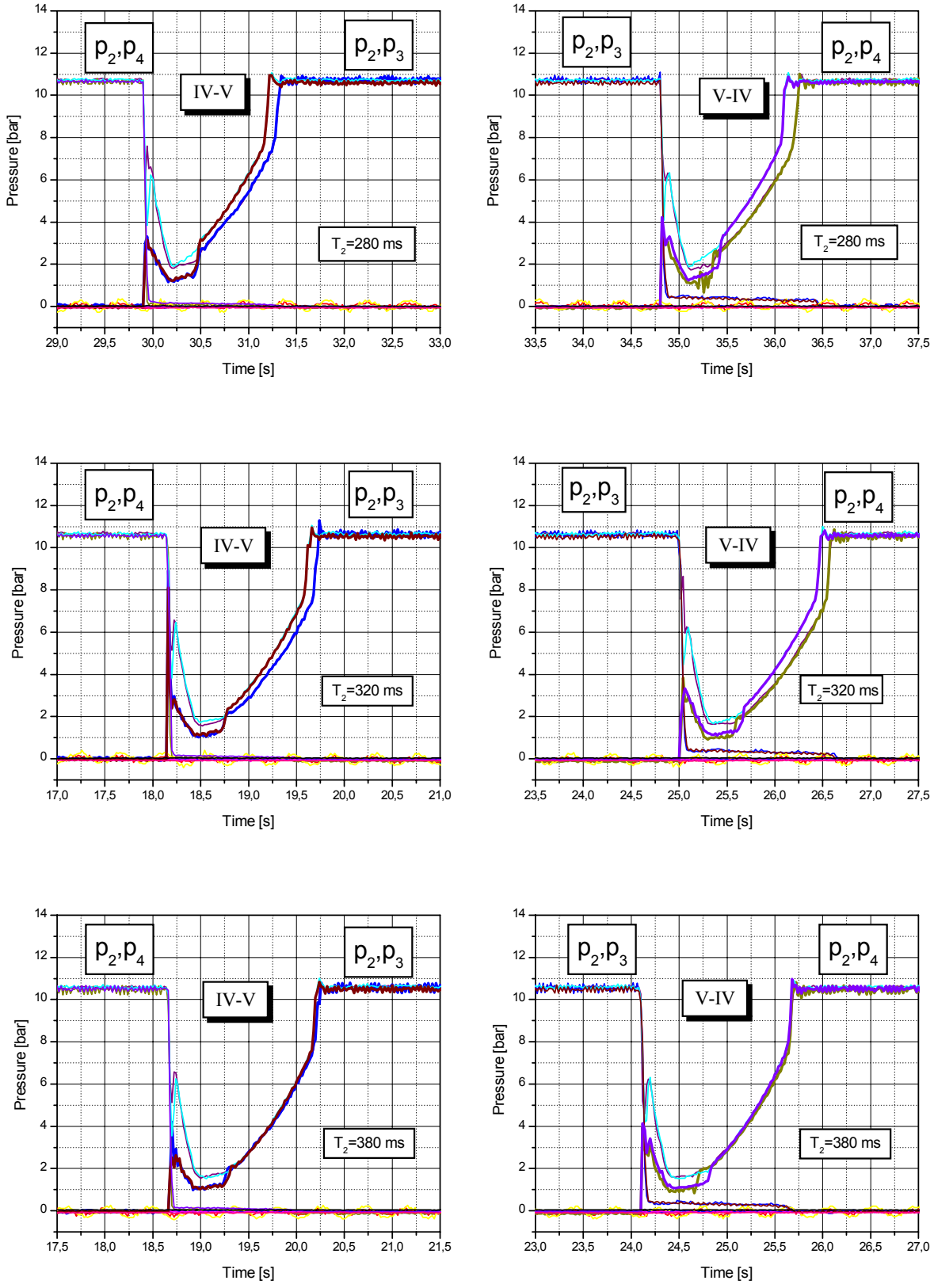


**Figure 7.** Change of pressure in gearbox friction clutches with different software parameters

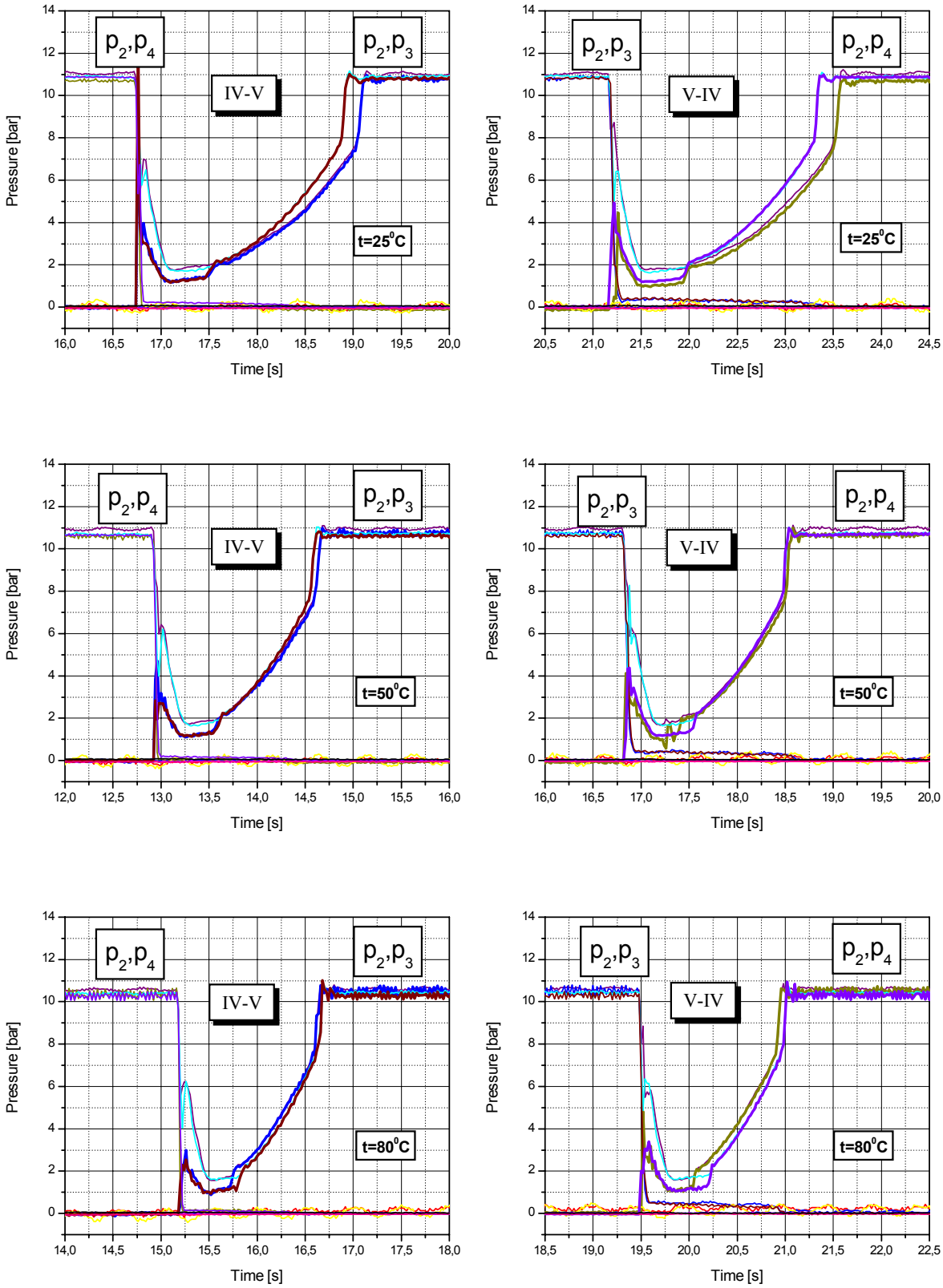


**Figure 8.** The influence of working temperature on the transient process

system development. The possibility of affecting the transient response by changing control software parameters is the result of applying the original solution for the control of the transmission with two planetary gearboxes.

The results of the GC TRONIC system testing, presented in Figure 8, show the influence of working conditions (oil temperature in the hydraulic system) on the transient response flow and duration. Obviously the engagement process of friction clutches is faster when operating oil has higher temperature. Therefore that the transient response is considerably shorter.

In order to view the advantages of the GC TRONIC system more completely in relation to the standard transmission control solution, comparative testings on the test

stand under load with a real engine and the transmission with one gearbox were carried out. A number of measurement parameters are registered. Based on them we established quality parameters of the transient response. We will not describe in detail these testings due to the limited space.

In Fig. 9 and 10, parallel notes of some parameters, measured during the gear change from the second to the third gear ratio on the test stand, with and without the use of the GC TRONIC system are pressented. The marks of measurement values are presented in Figures 9 and 10:

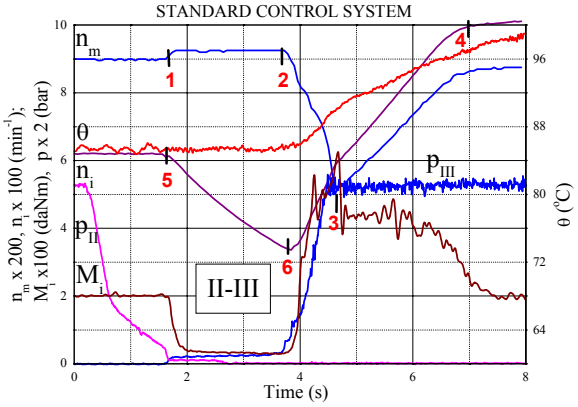


**Figure 9.** Transient response parameters measured on the test stand with the standard control system

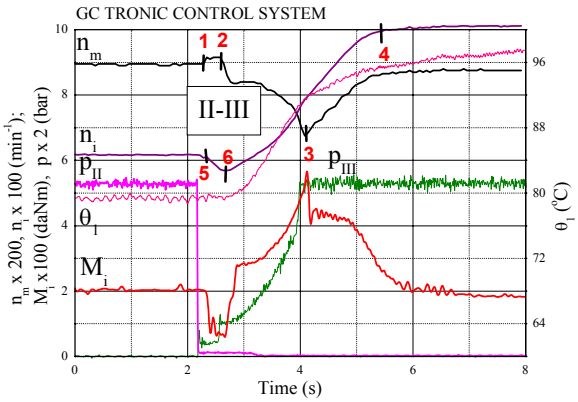


**Figure 10.** Transient response parameters measured on the test stand with the GC TRONIC control system

$n_m$ - engine crankshaft speed,
$n_i$ - output shaft speed,
$M_i$ - external load of gearbox output shaft,
$P_{II}$ - pressure in the friction clutches of lower gear ratio,
$P_{III}$ - pressure in the friction clutches of higher gear ratio and
$\Theta$ - temperature on the friction surface of the friction clutches.

The transient responses, presented in Fig.9 and 10, indicate significant advantages of the GC TRONIC system, as seen in Table 1. As a result, we can expect for the vehicle with the new transmission control system to have better mobility than the vehicle with the standard transmission control system.

The transient response testings with the GC TRONIC system proved that, during the gear change in both gearboxes, the friction clutches are engaged continually and synchronically. It represents the fulfillment of one of multiple demands for high-quality system functioning.

**Table 1**

| Transient response parameters | Time interval | Standard control system | GC TRONIC control system |
|---|---|---|---|
| Transient response duration | 1-4 | 5.30 s | 3.16 s |
| Transient response engagement time | 1-3 | 2.96 s | 1.84 s |
| Power flow interruption | 1-2 | 2.00 s | 0.32 s |
| Engine speed drop during the transient response | 2-3 | 43 % | 25 % |
| Speed drop of gearbox output shaft | 5-6 | 45 % | 8 % |
| Dynamic moment peak value | - | 622 daNm | 558 daNm |
| Temperature increase on the friction surface of the friction clutches | - | 13.1 °C | 18.0 °C |

## Conclusions

The review of the new control system concept for the transmission with two planetary gearboxes and the presented testing results proved the following:

- the realized GC TRONIC control system is a unique, original and modern solution of transmission system, used for the first time in the mentioned transmission concept,
- high-level of transmission control automatization is achieved due to the application of the original gear change process control,
- performed tests confirmed the fulfillment of given requirements and indicated the advantages of this system in relation to the existing solution,
- results of conducted researches present important scientific contribution to the control of high-speed tracked vehicle transmissions,
- conducted researches present a base for further development of this system, which is relevant for modernization of T-72 tanks and its variants,
- conducted researches are significant for development of similar transmission control systems for different types of vehicles.

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# Novi koncepti sistema upravljanja tenkovskom transmisijom s dva planetarna menjača

**U sklopu automatizacije postojećeg rešenja sistem upravljanja transmisijom s dva menjača brzohodnog guseničnog vozila, realizovan je novi koncept sistema, nazvan GC TRONIC, zasnovan na primeni elektrohidrauličkih komponenata s mikrokontrolerom u ulozi elektronskog uređaja za upravljanje. Sistem obezbeđuje automatizovan i kontrolisan proces promene stepena prenosa pod opterećenjem, bez upotrebe komande glavne spojnice*) koja se koristi samo pri polasku vozila iz mesta. U radu su date osnovne informacije o ovom sistemu i prikazane njegove izlazne karakteristike ostvarene u procesu promene stepena prenosa na probnom stolu s realnom transmisijom.**

*Ključne reči:* **brzohodno gusenično vozilo, transmisija, mikrokontroler, GC TRONIC sistem.**

*) Pod komandom glavne spojnice u transmisiji s dva planetarna menjača, podrazumeva se komanda pomoću koje se vrši rasterećenje frikcionih sklopova od pritiska ulja i, na taj način, ostvaruje potreban prekid toka snage.

# Une nouvelle conception du système de commande de transmission à deux boîtes de vitesses planétaires chez les chars

**Sur le plan de l'automatisation du système existant de commande de transmission à deux boîtes de vitesses chez les véhicules chenillés à grande vitesse, une nouvelle conception du système, GC TRONIC, est réalisée en utilisant les composants électrohydrauliques avec le microcontroleur comme le dispositif de commande électronique. Le système permet le changement de vitesses automatique et contrôlé sous charge, sans utilisant l'embrayage principal*) qui n'est employé que pendant le démarrage. Les informations principalles sur ce système sont données aussi bien que ses caractéristiques de sortie réalisées pendant le changement de vitesses sur le banc d'essai avec la transmission réelle.**

*Mots-clés*: **véhicule chenillé à grande vitesse, transmission, microcontroleur, système GC TRONIC.**

*) La commande de l'embrayage principal dans la transmission à deux boîtes de vitesses planétaires est la commande qui décharge les assemblages à friction de la pression de l'huile en provoquant ainsi la coupure nécessaire de l'écoulement de prissance.