UDK: 358.118:681.527.3
COSATI: 19-03, 13-06

Realization of Steering Function in Two Planetary Gearbox Transmission by GC TRONIC Control System

Zlatomir Živanović, PhD (Eng)[1)]
Mladen Pantić, PhD (Eng)[2)]
Miodrag Milić, MSc (Eng)[2)]

The paper presents some results of investigation of steering process involving the new control system, named GC TRONIC. Testing of the new control system was carried out by simulation of the steering process on the corresponding test stand. Some results of test which were compared with the results obtained by testing the existing control system are also presented in the paper.

Key words: **tracked vehicle, vehicle control, vehicle transmission, steering, electro-hydraulic system, electro-hydraulic control, GC TRONIC system.**

Introduction

IT is well known that tracked vehicles possess good characteristics and high field mobility. However, the transmission and steering systems are very complex because different speeds of the tracks are required in the steering process. Transmissions of the tracked vehicles were, most often, realized by two power flows and differential output transmissions where the flows are superimposed in order to realize the steering of the vehicle.

There are, however, other solutions which use the two planetary gearboxes differential gears for the realization of the steering process. The transmissions based on two planetary gearboxes, the solution which has been applied to a number of tracked vehicles, the so called «eastern concept», is characterized by the fact that the gearboxes integrate the functions of straight motion, steering and braking of the vehicle.

The steering of a tracked vehicle having two planetary gearboxes is accomplished on the basis of the difference between the transmission ratios of the gearboxes. Different transmission ratios in the planetary gearboxes are obtained by activating the corresponding friction clutches. The engagement of the friction clutches in a STANDARD system of transmission control is performed by the oil applied through the executive hydraulic units activated by mechanical commands.

The requirements for increasing the performances of this type of vehicles led to modifications of the existing solution and the development of an entirely new control system. A functional model of an electro-hydraulic control system, called the GC TRONIC, which provides a high degree of transmission automation, was developed. The functional model of the new control system, based on electro-hydraulic components and electronic control by a controller, was developed in the Military Technical Institute in Belgrade [1,2,3,4]. The system allows, in the straight motion of a vehicle, the gear change under load which involves minimum interruption of the power flow and continuous engagement of the friction clutches. In addition, the system provides all the functions of the transmission in the steering process, due to the original solution of the electro-hydraulic units and electronic control by means of a controller.

Steering by standard control system

The planetary gearboxes of the considered tracked vehicle can realize (5+1) gears. Each gear (in straight motion or steering) is achieved by activating two friction clutches in each gearbox. The sequence of activation of the friction clutches in the planetary gearboxes during a straight motion or steering process is presented in Table 1 [1].

Table 1. Sequence of activation of friction clutches in planetary gearboxes

MOTION		STRAIGHT MOTION						STEERING											
GEARBOX		LEFT/RIGHT						INTERNAL						EXTERNAL					
GEAR		I	II	III	IV	V	R	I	II	III	IV	V	R	I	II	III	IV	V	R
FRICTION CLUTCHES	F1			■							■					■			
	F2				■	■						■					■	■	
	F3	■				■	■		■	■	■			■				■	■
	F4	■	■	■	■			■	■			■	■	■	■	■	■		
	F5						■	■					■						■
	F6		■							■					■				

Fig.1 shows a block diagram of the standard control system for performing the process of steering. This part of the system consists of the steering command, the executive hydraulic units for each gearbox, including the source of hydraulic energy, and the friction clutches in the planetary gearboxes. The oil flow into the corresponding friction

1) Institute of Nuclear Sciences "VINČA", Depart. for I.C. Engines and Vehicles, 11001 Belgrade, PO Box 522, SERBIA
2) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

clutches of the internal gearbox is accomplished by the mechanical action of the steering levers on the corresponding components of the hydraulic units, causing a gear change. At the same time, the existing gear is retained in the external gearbox, thus the control pressure increases due to the increased resistance in the external track during steering.

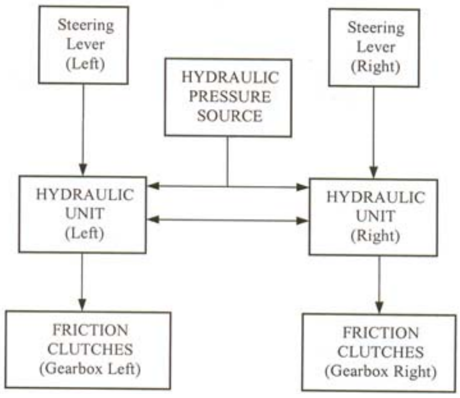

Figure 1. Block diagram of standard control system

The hydraulic units, Fig.2 (only one unit is shown), are complex hydraulic components which integrate the functions of regulation of the control pressure and distribution of oil into the corresponding friction clutches during gear changes in the process of steering.

Oil flow directions are performed by elements A and B of rotational control unit, Fig.3. The elements achieve proper angle positions by mechanical levers. The oil communication towards friction clutches of inner gearbox provides the activation of lower gear ratio. This communication is realized by the elements of rotational control unit.

Apart from the rotational unit, a hydraulic unit contains: the pressure regulator, unit for increasing the steering pressure in the process of turning and elements of output commands.

Some components of the executive hydraulic unit which participates in the steering process in the fifth gear are shown in Fig.4. The pressure in the transmission control system is maintained at the required level by a regulator pressure valve (RP_L). The distribution of oil to the friction clutches is accomplished by mechanical action of the steering lever (SL_L) on the rotational valve (RtV_L). The distribution of oil to the friction clutches is accomplished by mechanical action of the command for changing gear ratio on the same valve, during straight motion.

Figure 2. Hydraulic units of STANDARD CONTROL SYSTEM

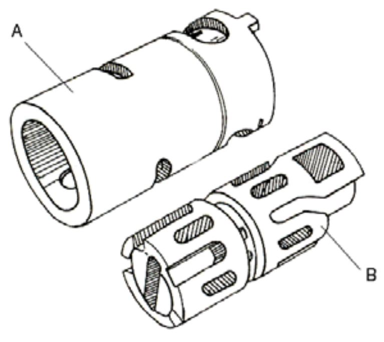

Figure 3. Rotational valve elements

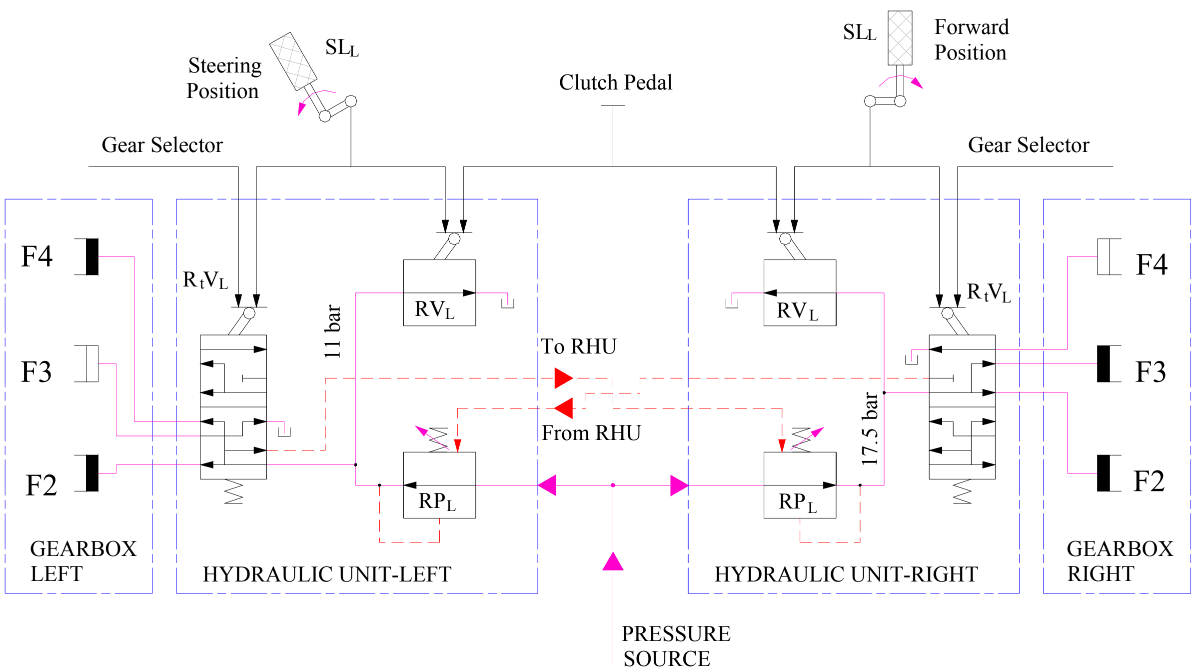

Figure 4. STANDARD CONTROL SYSTEM components in steering position

The required disengagement of the friction clutches in the gear change process (both in straight motion and in steering) is accomplished by means of mechanical action of the clutch pedal and steering lever on the relief valve (RV_L). A hydraulic signal is formed and sent to the external (right) hydraulic unit (RHU) of the external gearbox via the rotational valve in the left hydraulic unit of the internal gearbox in the steering process in order to act on the pressure regulator and increase the control pressure in the external gearbox. The role of the internal gearbox is played by the left gearbox whereas the right gearbox plays the role of the external gearbox (Fig.4). The pressure in the engaged friction clutches of inner gearbox in the process of turning is 11bar while in friction clutches of external gearbox it increases up to 17.5bar.

Some of the components of the system serving for relieving the friction clutches in the process of steering are shown schematically in Fig.5. The relief of the pressure of the friction clutches is accomplished by mechanical action on the spring of the pressure regulator through a system of levers and a profiled cam plate which is coupled to the steering handle.

The principle of friction clutches engagement / disengagement in the process of turning is shown in Fig.6. In the position "0" of the cam plate, Fig.5, the pressure regulator maintains the function pressure in the control system. By steering the cam plate to position '1' a spring acts on the piston of the pressure regulator and reduces the pressure in the system down to zero (Fig.6).

Further steering of the cam plate to position "2" leads to the phase of steering due to the rotational valve, already in position "1", is switched to a reduced gear ratio, and the pressure in the system of the internal gearbox increases to the nominal value, Fig.6. The described turning phase (1-2-3) represents the first turning phase i.e. entering the turning, when the lower gear ratio is engaged and the turning is performed with the determined radius. The reverse process (3-2-1) represents the second phase – the output of turning and the establishment of straight motion.

The pressure change character (pressure modulation) in the process of turning, during the engagement of the lower gear ratio, is determined by the cam plate profile and its interaction with pressure regulator elements. The need for a swift change of direction during the vehicle turning and the stabile steering requires a fast response of the system with the engaged friction clutches.

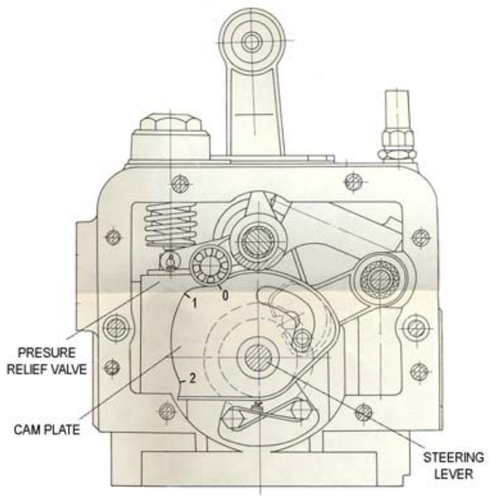

Figure 5. Components for relieving friction clutches in the process of steering

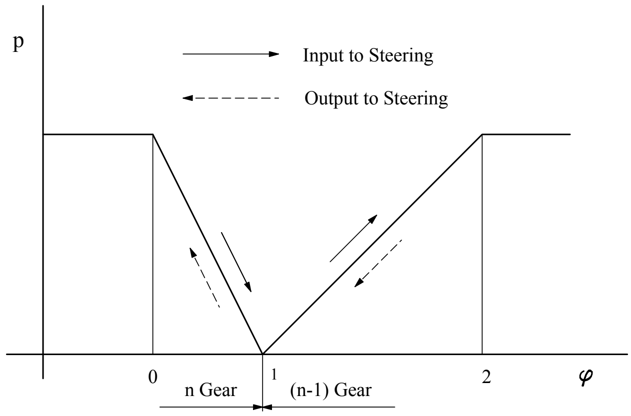

Figure 6. Pressure change in the control system in the steering position

In order to identify the character of the transient process during steering, experimental measurements of characteristic parameters of the vehicle having a standard control system have been carried out. The pressures in the corresponding friction clutches of both gearboxes were measured in both straight motion and during steering.

Figsures 7 and 8 show diagrams of variations of pressures in the friction clutches for both phases of the steering process in the fifth gear of the standard control system. The first phase is starting the steering process and the second is finishing it.

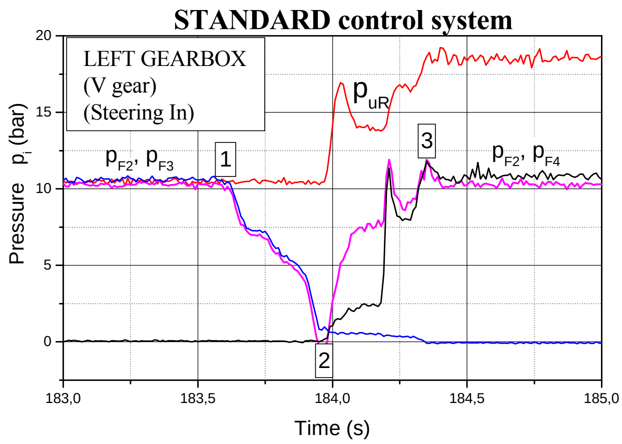

Figure 7. Change of pressure in friction clutches in the first phase of steering with STANDARD CONTROL SYSTEM

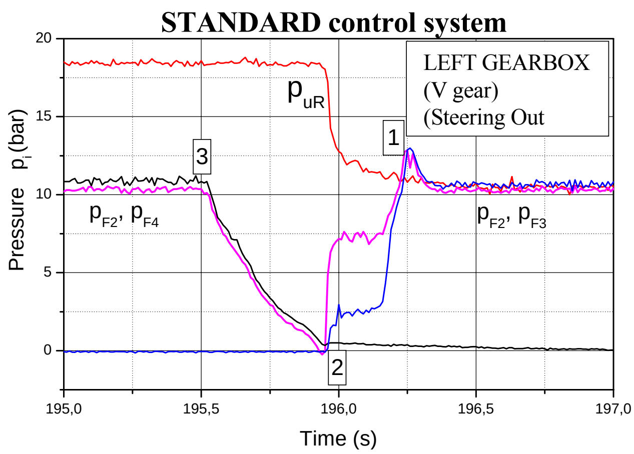

Figure 8. Change of pressure in friction clutches in the second phase of steering with STANDARD CONTROL SYSTEM

During the first phase of steering, Fig.7 [1], which consists of two stages, the pressure relief in the friction clutches F2 and F3 is accomplished first, stage (1-2), and in the stage (2-3) the lower gear (IV) is engaged by activating the friction clutches F2 and F4. The pressure in the control system of the external gearbox increases during this stage. The steering lever is in its extreme position in this phase.

The second phase, Fig.8 [1], finishes the steering which is accomplished by returning the steering lever to its initial position. In this phase there are also two stages, the first (3-2) when the pressure is relieved in the friction clutches F2 and F4 of the lower gear (IV) and the second (2-1) when the pressure in the friction clutches F2 and F3 of the higher gear (V) is established.

New control system concept

The new control system concept for the transmission with two planetary gearboxes, named GC TRONIC [3, 4], is based on the use of electro-hydraulic components and the electronic control by the microcontroller. The system provides the high-level automatization of gear change process in order to accomplish the following:

- facilitate vehicle steering,
- improve vehicle performance due to the gear change under load,
- decrease dynamic and thermal loads in the transmission,
- reduce fuel consumption,
- decrease gear change control time.

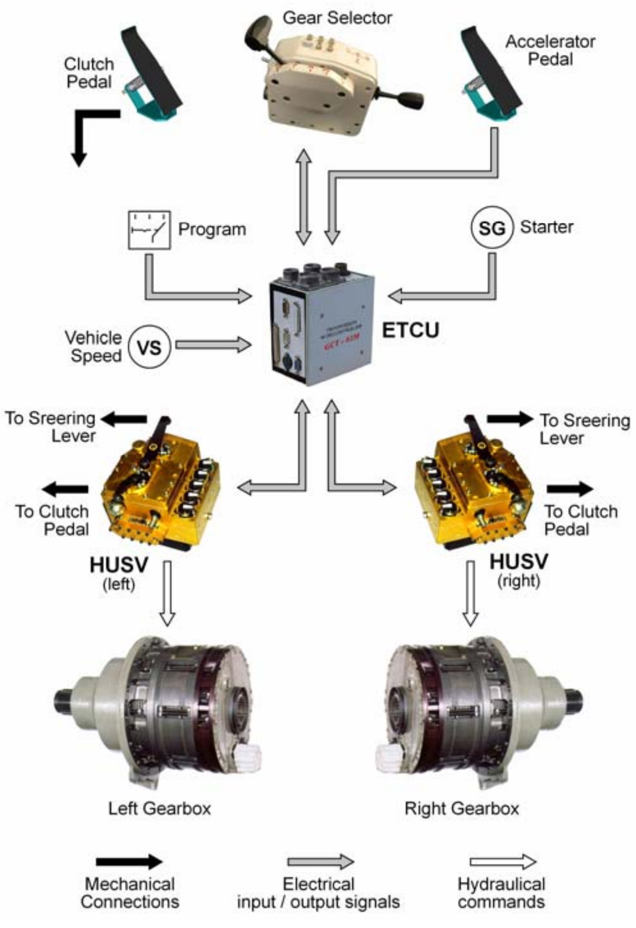

Figure 9. GC TRONIC control system layout

The disposition of the GC TRONIC system main components with planetary gearboxes is shown in Fig.9 (steering lever is not shown). The system consists of the following:

- Commands, i.e. gear selector, clutch pedal, steering lever and accelerator pedal,
- ETCU (Electronic Transmission Control Unit)
- HUSV (Hydraulic Units with Solenoid Valves),
- Gearboxes with friction clutches and
- Other system components and sensors.

The control of operation of the system components, shown in Fig.9, is accomplished in various ways: by mechanical couplings, electrical signals or hydraulic action.

Steering by GC TRONIC control system

New components of the GC TRONIC system compared to the standard solution system are the following:

- newly designed steering levers SL_L,
- position sensors of the steering levers – potentiometers PT_L,
- hydraulic-controlled valves (spool valves) for the gear change SV_L,
- solenoid valves for commanding the gear changes (shift solenoids) SS_L,
- solenoid valves for increasing the pressure in the external gearbox (increasing solenoids) IS_L and
- electronic controller ETCU.

Fig.10 shows some of the components of the electro-hydraulic (GC TRONIC) control system [1] which participates in the steering process in the fifth gear.

The operation of the system during the process of steering consists of the following:

- Pulling the steering lever, Fig.10, via a mechanical coupling acting on the pressure relief valve RV_L of the engagement friction clutches and simultaneously generating a voltage signal in the potentiometer PT_L which is further introduced to ETCU. When the potentiometer voltage reaches a certain specified level, the electronic controller generates a control signal for the solenoid valve SS_L which activates the spool valve SV_L to change the gear ratio in the internal gearbox. Simultaneously, a control signal is generated for the increasing solenoid IS_L which generates a hydraulic signal in order to increase the pressure in the external gearbox.
- The pressure in the engaged friction clutches of inner gearbox in the process of turning is 11bars but in friction clutches of external gearbox it increases up to 17.5bar.
- The modulation of the pressure in the friction clutches during the steering process is accomplished in the same way as in the standard system. The operation of the system during the steering process is identical in each gear. The use of the controller allows a precise definition of the control signals and allows obtaining an optimum transient process when gear changing in both straight motion and steering.

Testing the GC TRONIC system

The steering functions of the GC TRONIC control system were successfully tested in laboratory conditions on the test stand (Fig.11) with real transmission. During testing, with the help of the data acquisition device, many testing parameters were recorded, i.e. pressures of friction clutches in both gearboxes and electrical signal of the potentiometers.

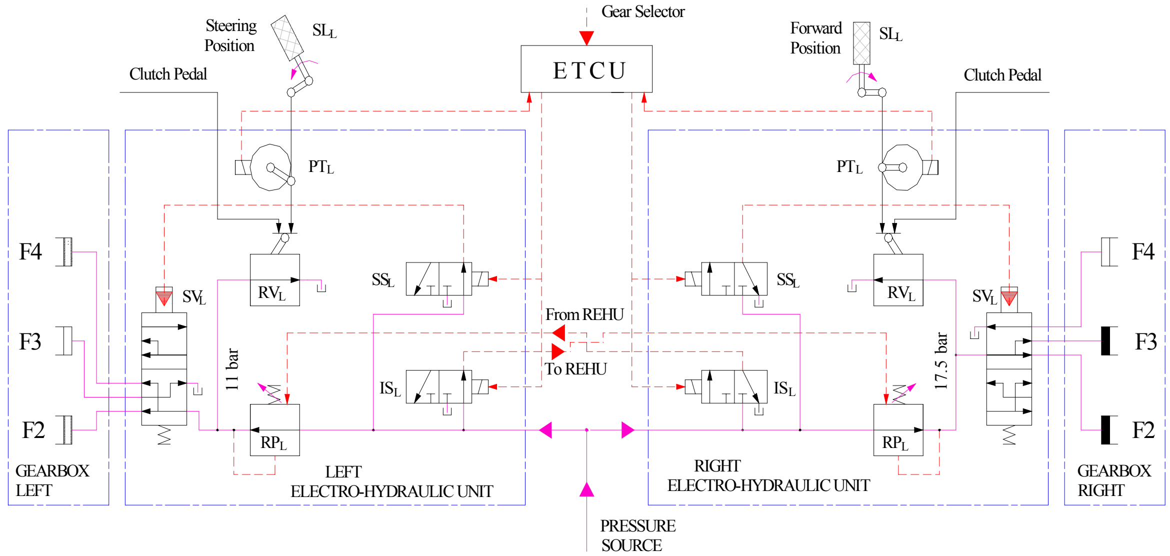

Figure 10. GC TRONIC control system components in the steering position

The entire testing of the GC TRONIC system was realized in a few phases of component testing and whole system testing. The most important kinds of testing [3,4] are the following:

- functional testing,
- dynamic testing,
- gear change process testing and
- testing of the steering process.

Test results of GC TRONIC system related to the process of turning will be presented in the paper.

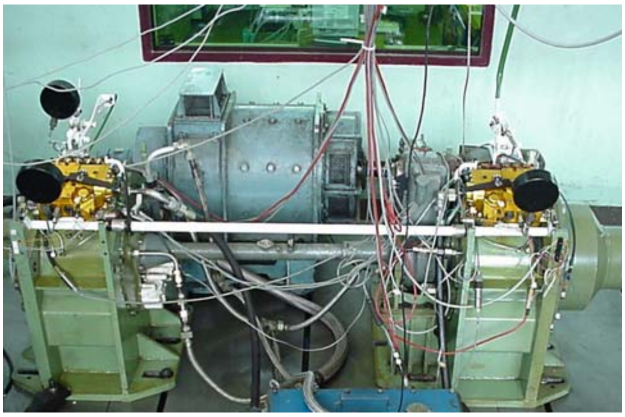

Figure 11. GC TRONIC control system on the test stand

The test of GC TRONIC system related to achieving turning function consists of the following processes:

- preliminary establishment (out from the test stand) of characteristics of potentiometers built in by the registration of generated voltage dependence on the turning angle,
- determining the value of the generated voltage signal of potentiometers built in during the process of turning at which the pressure in the friction clutches is minimal,
- software adjustment according to the obtained data,
- turning simulation on the test stand, in each gearbox and in each gear ratio, registering all measurement parameters,
- handling and analysis of the measurement results and
- software correction aiming at obtaining the optimal transient process and turning realization in all gear ratios.

Figures 12 and 13 show both phases of the steering process in the fifth gear with the GC TRONIC system, obtained by the simulation of the steering on the test stand [1]. The control pressures in all the friction clutches of both gearboxes and the voltage generated by the potentiometer in this case were measured.

The gear change in the internal gearbox occurs at a specified value of the voltage signal generated by the potentiometer which is mechanically coupled to the steering lever. The value of the control voltage of the potentiometer was determined experimentally and was found to correspond the voltage which is generated when the friction clutches are relieved, by activating the steering handle.

The character of the pressure change in the friction clutches shows that the new control system in the steering process realizes the required output characteristics. The existence of various sensors, actuators, and controllers in the system allows a precise definition of the transient process in all gear changes.

During the first phase of steering, Fig.12 [1], which evolves in two stages, pressure relief in the friction clutches F2 and F3 is accomplished first, stage (1-2), and stage (2-3) the lower gear is engaged by activating the friction clutches F2 and F4. During this stage, the pressure in the control system of the external gearbox increases. In this phase the steering lever is in its extreme position.

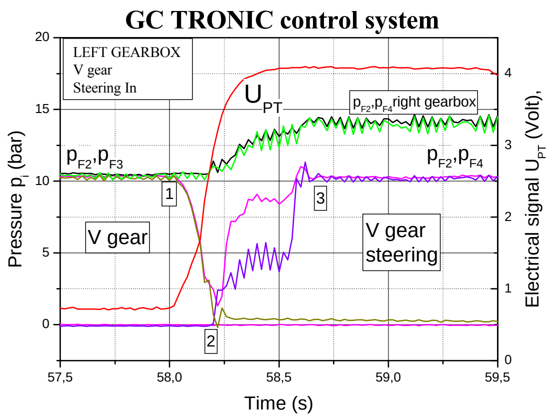

Figure 12. Pressure change in friction clutches in the first phase of steering with GC TRONIC CONTROL SYSTEM

The second phase, Fig.13 [1], finishes the steering by returning the steering lever to its initial position. There are also two stages in this phase. The first (3-2) when the pressure is relieved in the friction clutches F2 and F4 of the lower gear and the second (2-1) when the pressure in the friction clutches F2 and F3 of the higher gear is established.

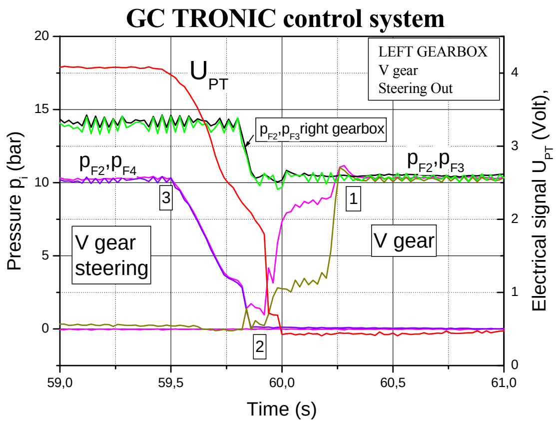

Figure 13. Change of pressure in the friction clutches in the second phase of steering with GC TRONIC CONTROL SYSTEM

The typical records of the measured characteristics which were registered by the GC TRONIC control system during steering in the left gearbox in all gears are shown in Figures 14 and 15. Diagrams in Fig.14 show the measured characteristics of the left gearbox in each gear during the first phase of steering. Diagrams in Fig.15 show the measured characteristics of the left gearbox in each gear during the second phase of steering. All measurement parameters were recorded at the oil temperature of 80°C in the transmission.

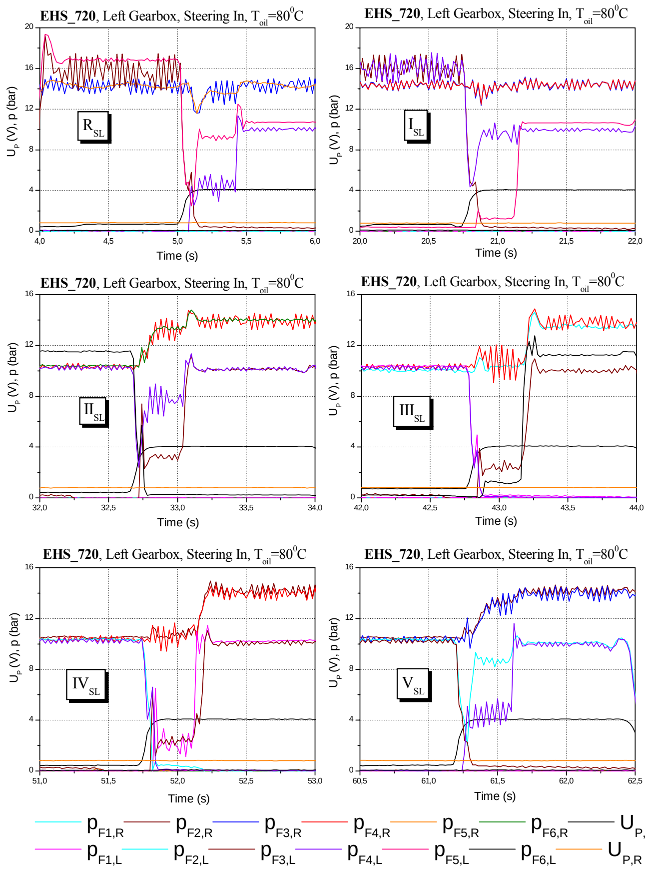

Figure 14. Measurement values which were registered by GC TRONIC control system in gearboxes in each gear during the first phase of steering on the left

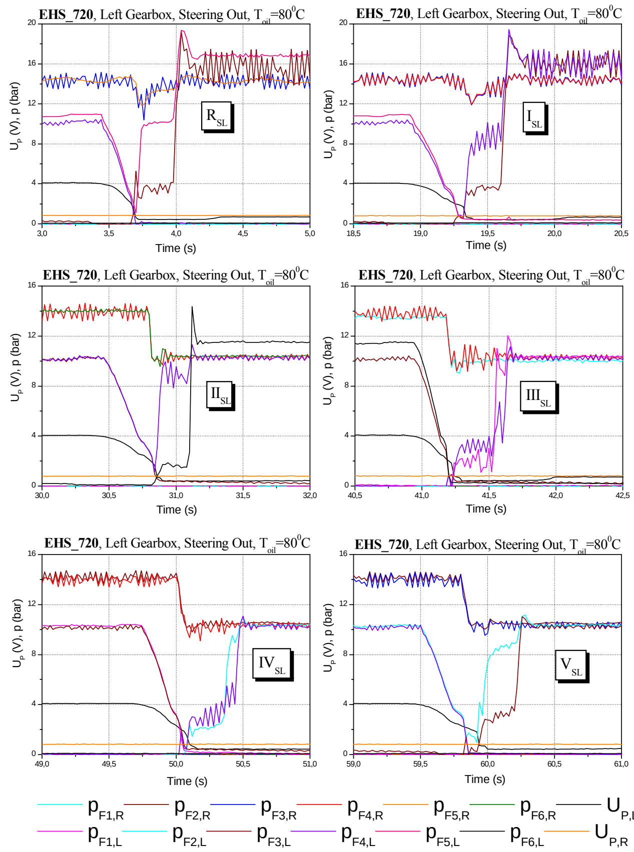

Figure 15. Measurement values which were registered by GC TRONIC control system in gear boxes in each gear during the second phase of steering on the left

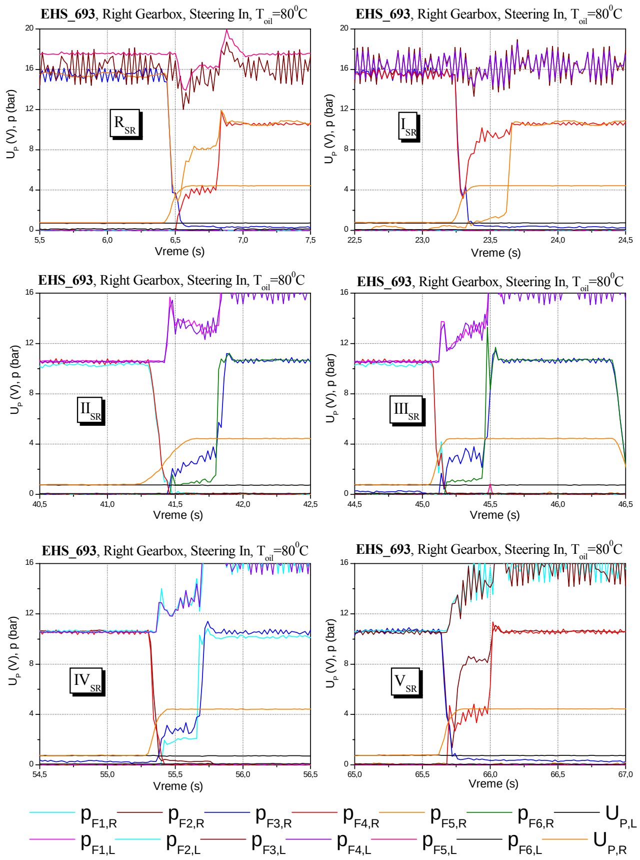

Figure 16. Measurement values which were registered by GC TRONIC control system in gearboxes in each gear during the first phase of steering on the right

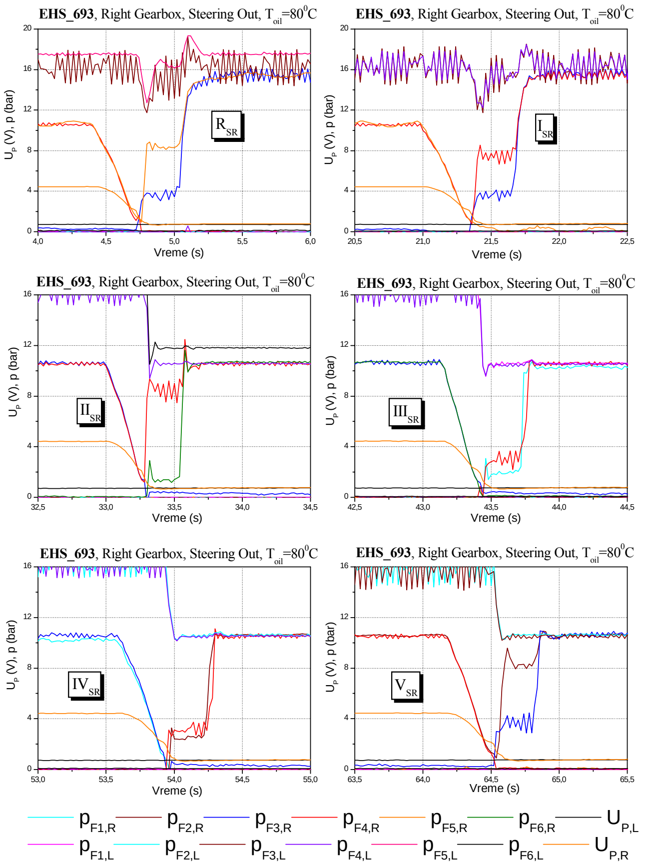

Figure 17. Measurement values which were registered by GC TRONIC control system in gearboxes in each gear during the second phase of steering on the right

Typical records of the measured characteristics registered by the GC TRONIC control system during the steering in the right gearbox in all gears are shown in Figures 16 and 17. Diagrams in Fig.16 show the measured characteristics of the right gearbox in each gear during the first phase of steering. Diagrams in Fig.17 show the measured characteristics of the right gearbox in each gear during the second phase of steering. All measurement parameters were recorded at the oil temperature of 80ºC in the transmission.

The analysis of each diagram which represents the process of turning shown in Figures 14 - 17, indicates that GC TRONIC system provides generation of the required output characteristics during turning which is characterized by the following:

- correct combination of friction clutches engagement in each gear ratio according to requirements given in Table 1,
- possibility of friction clutches unload from the oil pressure before each gear change in the inner gearbox (from start to finish of the turning),
- increasing or decreasing of pressure in the outer gearbox up to the desired value according to the turning phase,
- stabile characteristic of potentiometers built in the generation of voltage signals and
- duration of the transient process.

It is shown that components of the system function correctly and the parameters of software were defined accurately.

Conclusion

Testing of the electro-hydraulic control system carried out for the purpose of checking its functioning during the process of steering of high speed tracked vehicle show the following:

- the concept of the adopted solution of the system and selection of the system components were correct,
- the operational requirements, in accordance with the algorithm which is implemented as an electronic controller, were fulfilled,
- the required output characteristics, i.e. the desired law control of the friction clutches, were achieved,
- optimization of the transient process in all phases of the steering process is possible,
- the application of the electro-hydraulic components for an overall modernization of the concept of transmission control with two planetary gearboxes was justified, and
- a unique attempt was made to present an automatic control of this type of transmission in the proposed way.

References

[1] ŽIVANOVIC,Z., MILIĆ,M.: *Realization of Steering Function in the Transmission of a Tracked Vehicle Having Electro-Hydraulic Control System*, International Congress Motor Vehicles & Motors 2006, Kragujevac, CD MVM20060024, ISBN 86-80581-95-X, 2006.

[2] ŽIVANOVIC,Z.: *Automatization of transmissions for high-speed tracked vehicle*, Scientific Technical Review, 1998, Vol.XLVIII, No.4, pp.114-119.

[3] ŽIVANOVIC,Z., Jerkin,G.: *New Transmission Control System Concept for High-Speed Tracked Vehicle with Two Planetary Gears*, XIX International Conference 'Science and motor Vehicles 2003, CD YU-03070, Belgrade, 2003.

[4] ŽIVANOVIC,Z., Jerkin,G.: *New Control System Concept for tank transmission with two planetary gearbox*, Scientific Technical Review, Belgrade, 2003, Vol.LIII, No.3, pp.14-21.

Received: 16.12.2006.

Ostvarivanje funkcije zaokreta u transmisiji sa dva planetarna menjača pomoću GC TRONIC sistema za upravljanje

U radu su prezentirani neki rezultati istraživanja procesa zaokreta sa novim sistemom upravljanja, koji je nazvan GC TRONIC. Testiranje novog sistema za upravljanje obavljeno je simuliranjem zaokreta na odgovarajućem probnom stolu. U radu su predstavljeni, kroz odgovarajuće izlazne karakteristike, samo neki rezultati realizovanih ispitivanja koji su, zatim, upoređeni sa rezultatima koji su dobijeni ispitivanjem postojećeg sistema upravljanja.

Ključne reči: **gusenično vozilo, upravljanje vozilom, transmisija vozila, zaokret, elektrohidraulički sistem, elektrohidraulično upravljanje, GC TRONIC sistem.**

Реализация функции управления в передаче с двумья планетными редукторами при помощи ГЦ ТРОНИЦ системы для управления

В настоящей работе представлены некоторые результаты исследования процесса управления с новой системой управления, которая получила название ГЦ ТРОНИЦ - система. Испытание новой системы управления проведено имитационным моделированием управления на тренажёре - т.е. на ответственном испытательном стенде. В работе через ответственные выходные характеристики представлены только некоторые результаты реализованных испытаний, которые потом сравниваны с результатамы полученными испытыванием уже существующей системы управления.

Ключевые слова: гусеничная повозка, управление повозкой, привод повозки, управление, электрогидравлическая система, электрогидравлическое управление, ГЦ ТРОНИЦ - система.

Réalisation de la fonction du tournant dans la transmission avec deux boîtes de vitesse planétaires à l'aide du système de commande GC TRONIC

Dans ce papier sont présentés les résultats des recherches sur le procès de tournant au moyen du nouveau système de commande appelé GC TRONIC. Le test du nouveau système de commande a été effectué par la simulation du tournant sur la table d'essai correspondante. A travers les caractéristiques d'entrée correspondantes, on présente dans ce travail seulement les résultats des essais réalisés qui, par la suite, ont été comparés avec les résultats obtenus pendant les essais du système de commande actuel.

***Mots clés*: véhicule à chenilles, conduite de véhicule, transmission de véhicule, tournant, système électro-hydraulique, commande électro- hydraulique, système GC TRONIC**