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GENERATING THE PRESSURE TO CONTROL THE GEAR RATIO OF A CONTINUOUSLY VARIABLE TRANSMISSION IN A CAR

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Summary

Continuously variable transmission used in gearboxes allows to reduce the driver's participation in the process of controlling the drive system while driving by using automatic gear ratio control, and due to its flexibility, enables the internal combustion engine to operate in the area of its greatest efficiency. Moreover, it can be used in hybrid drive systems using mechanical energy accumulators.

Finding references to empirical correlations including the effect of various signals interfering with the operation of a gearbox equipped with a continuously variable transmission in literature was very difficult, therefore the aim of this study was to bench test the impact of those signals and to define characteristics for controlling pressures in the transmission pulley actuators to achieve the preset gear ratio and the ability to transfer torque.

The study was conducted at a test stand simulating the behaviour of an internal combustion engine and the resistance to the movement of a car under steady and transient states.

The result were establishing the characteristics for controlling the pressure in the pulley actuators and finding the effects of temperature and rotational speed of pulleys. While verifying the interfering effect of temperature, it was observed that its effect on the oil was not critical. Temperature had the greatest impact on the operation of solenoid valves, which were responsible for the process of adjusting and maintaining the pressure.

Then, with the ability to control pressures in the pulley actuators, maps were created.

Keywords: continuously variable transmission, control, bench testing, gear box

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1. Introduction

Continuously variable transmission (CVT), also called a variator, allows for continuous adjustment of the gear ratio. As a result, the speed of a vehicle can change at a constant speed of the engine.

To realize the required gear ratio, automatic transmissions need actuators (clutches and brakes in planetary gears, variator pulley actuators) and verifying elements (sensors). Actuators are usually controlled by the oil pressure obtained by the appropriate control of a solenoid, often cooperating with a hydraulic amplifier which is a part of the electro-hydraulic control unit electrically connected to the control computer.

2. Tested gearbox

The study used a gearbox equipped with a continuously variable transmission operating in Nissan Micra K12 drive system. The transmission was equipped with a push belt. In this solution the output pulley unit was responsible for the belt tension, and the input pulley unit was responsible for shifting gears. The tested gearbox diagram is shown in Figure 1.

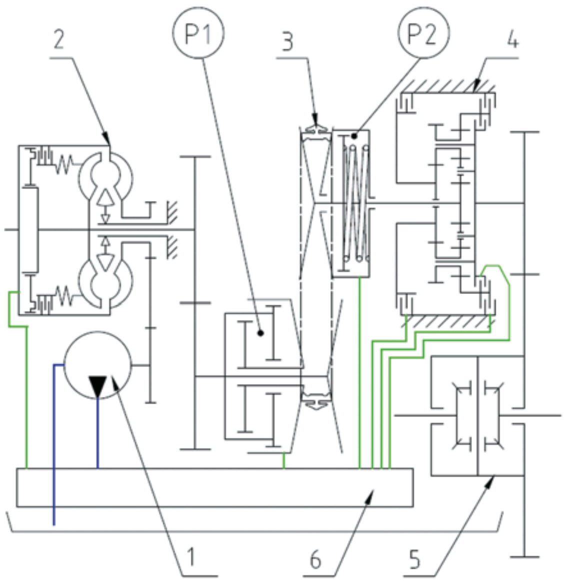

Fig. 1. Mechanical diagram of the tested gearbox

1 – oil feed pump, 2 – torque converter, 3 – push belt, 4 – Ravigneaux planetary gear, 5 – main gear, 6 – electro-hydraulic control unit, P1 – pressure in the input pulley actuator, P2 – pressure in the output pulley actuator

The test focused on creating characteristics for controlling the pressure in pulley actuators and gear ratios, and examining the interfering signals affecting the process of generating pressure and gear ratios. The part of the electro-hydraulic control unit block responsible for generating the pressure in pulley actuators, which in turn translates into the development of a pre-set gear ratio realized by the transmission, is shown in Figure 2.

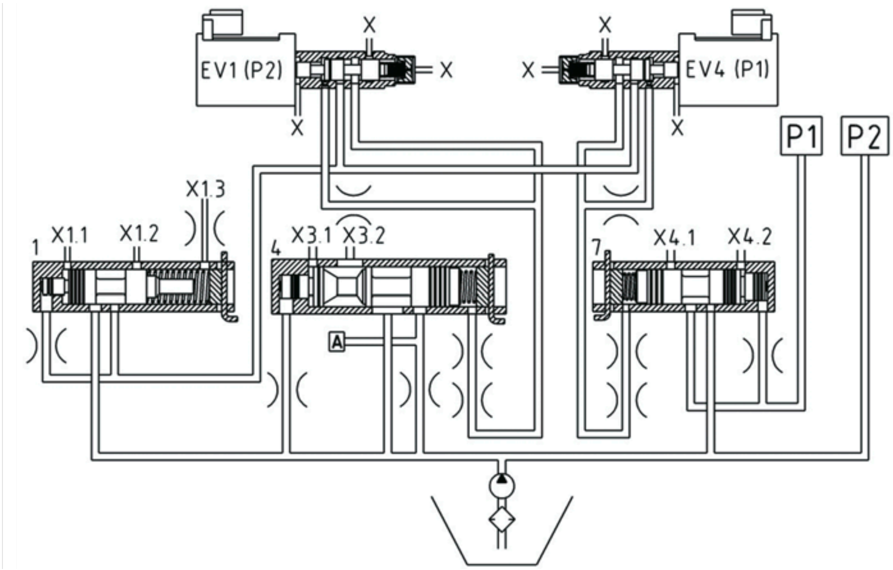

Fig. 2. Circuit diagram of an electro-hydraulic controller responsible for the generation of pressure on the pulleys

EV1, EV4 – solenoid valves, 1,4,7 – distributors, A – receivers responsible for the lubrication of the transmission belt and cooling oil, P1 – pressure in the input pulley, P2 – pressure in the output pulley, x – oil drain

The task of the spool valves 1, 4 and 7 is to stabilize the pressure of the liquid leaving the valve, regardless of changes in pressure of the liquid supplied to the valve, wherein the stabilized pressure is less than or equal to the supply pressure.

3. Maps of controlling the PWM signal in order to maintain the preset pressure

The first stage of the study was to define a map allowing to control pressures in the continuously variable transmission pulley actuators. This involved finding a PWM signal which allows to obtain the pre-set pressure to control pulley settings for a given value of the oil temperature. Examples of such maps are shown in Figures 3 and 4.

$$PWM_1 = f(P2,t) \quad (1)$$

$$PWM_4 = f(P1,t) \quad (2)$$

where: – the signal routed to the appropriate solenoid,
– pressure at the corresponding pulley,
– oil temperature.

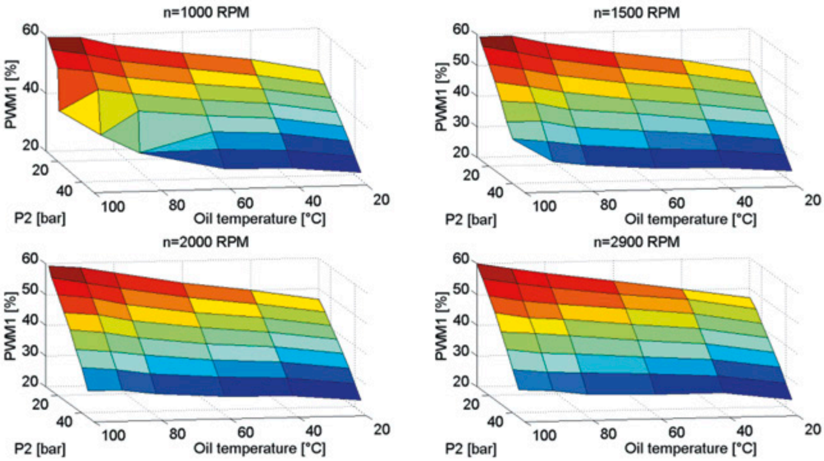

Fig. 3. Overview of maps for the output pulley

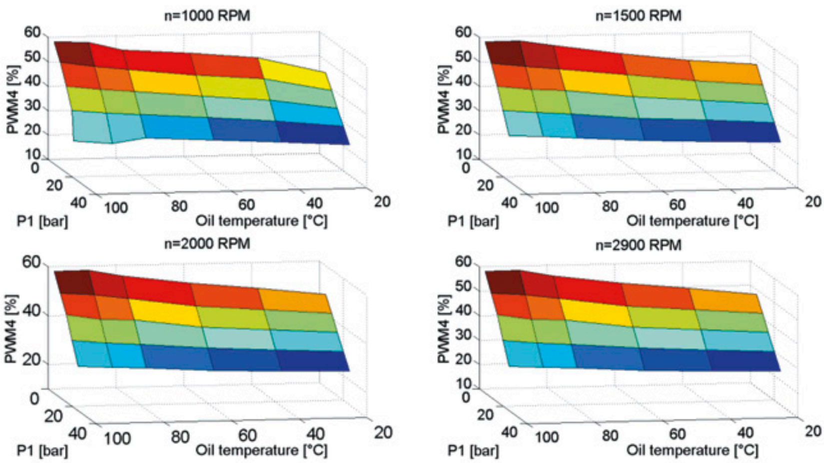

Fig. 4. Overview of maps for the input pulley

Charts presented in Figures 3 and 4 were prepared in steady conditions. This means that the measured pressure values were equal to the values of the preset pressure. The diagrams show that as the oil temperature increases, the preset value of the PWM signal required to achieve the same pressure increases – as can be seen in the plane cross-section of constant pressure maps shown in Figure 5.

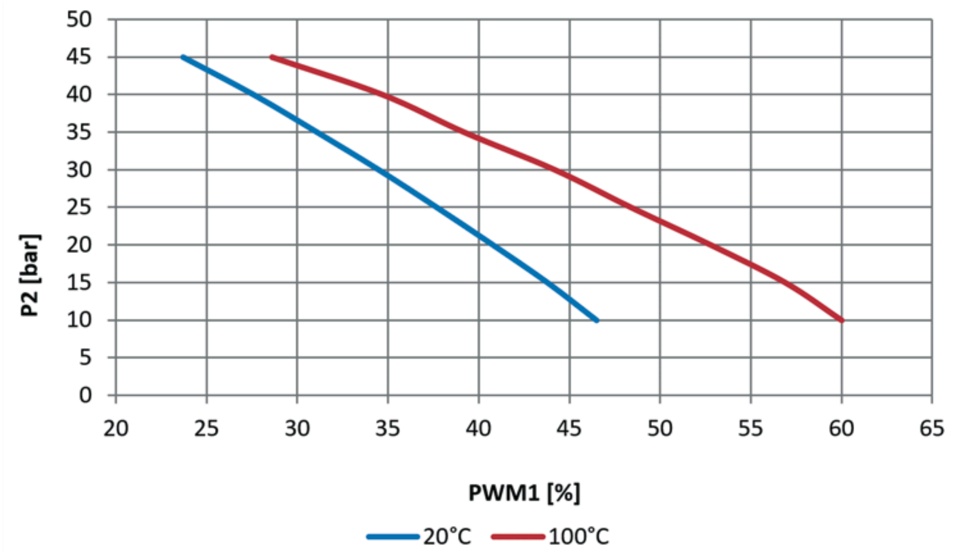

Fig. 5. The effect of temperature on the oil pressure in the actuator of the output pulley (n = 2000 RPM)

As it turns out, this phenomenon is not associated with the increase in the oil temperature, but with the increase of temperature in the solenoid coil resulting from the operation of the flowing current, since the coil resistance changes with temperature. The solenoid coil controlled by the maximum PWM heated up to a temperature of 115 °C, therefore we may suspect that the oil flow cooled it. Another important aspect is oscillation of the voltage within certain limits in the vehicle electrical system. In order to disambiguate the input signal, it is necessary to introduce the concept of the average current powering the solenoid valve. Figure 6 shows the characteristics of the output pressure of the solenoid as a function of the average current for various temperatures.

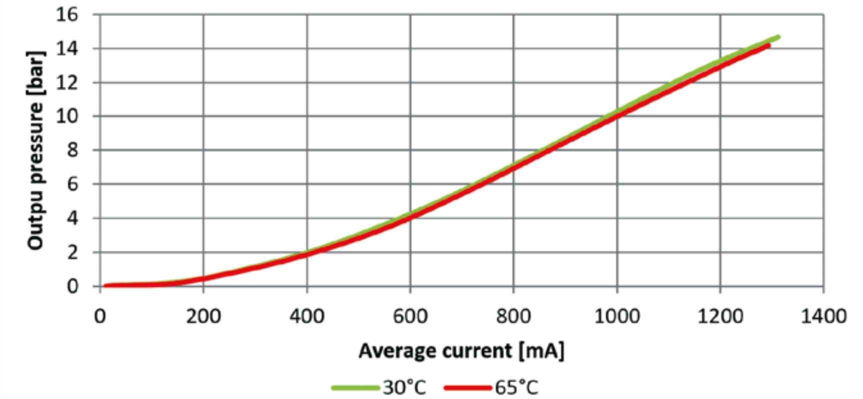

Fig. 6. The magnetic force as a function of the average current for various temperatures

The diagram in Figure 6 shows that by controlling the average current supplying the solenoid valve, it is possible, in an algorithm responsible for generating pressures in actuators of continuously variable transmission pulleys, to become completely independent from the temperature. Then there would be no need to know the characteristics of the solenoid valve in the form of:

$$P = f(PWM,t) \tag{3}$$

With the increase in the input speed, the PWM signal required to achieve the same pressure is increased slightly. This phenomenon is illustrated in Figure 7 showing the characteristics of the PWM signal as a function of the pressure P2 for the different input speeds.

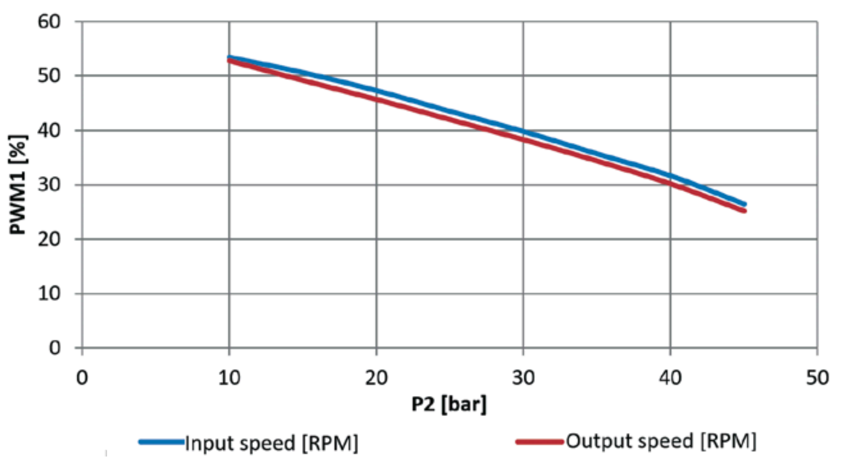

Fig. 7. The effect of input rotational speed on the pressure in the actuator of the output pulley (Toil = 60 °C)

This phenomenon is associated with the centrifugal force acting on the belt, resulting in the increased wrap radii of the belt pulley in respect to the flexibility of the belt.

4. Continuously Variable Transmission gear ratio control maps

The second stage of the work was to develop the map illustrating the preset gear ratio by changing the pressure P1 at the constant pressure P2.

$$P1 = f(I_{CVT}, P2). \tag{4}$$

Variable gear ratio is defined as:

$$I_{CVT} = \frac{\omega_{kp2}}{\omega_{kp1}} \tag{5}$$

where: ω_{kp2} – output pulley rotational speed

ω_{kp1} – input pulley rotational speed

At this stage of the study, the lever controlling the mode of gearbox operation was set in the Drive position, torque converter locking clutch was engaged, and the planetary gear was controlled at the ratio i = 1. The maximum torque at the input to the transmission was limited to 120 Nm.

Results were written down after stabilization of the gear ratio, therefore the setpoint values of pressure and gear ratio were equal to the values measured.

Figure 8 shows an example of the characteristics showing the P1 pressure values needed to realize the preset gear ratio at a constant pressure P2 prevailing in the chamber of the actuator responsible for the belt tension for different oil temperatures and various input rotational speeds of the gearbox not loaded with the braking torque.

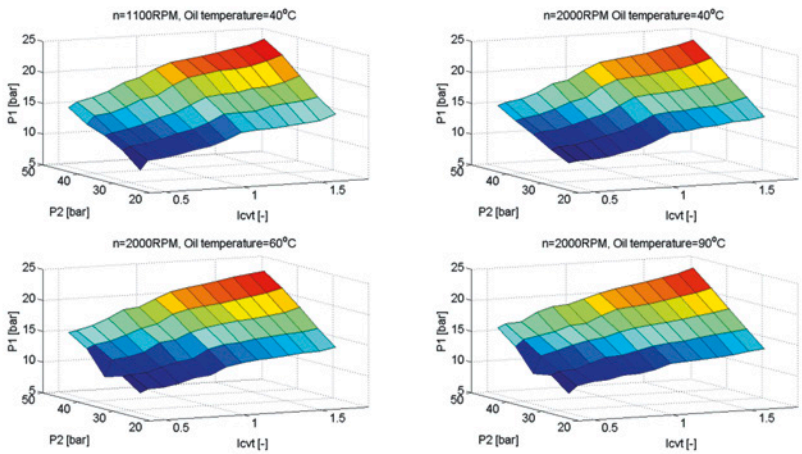

Fig. 8. Overview of pressure pairs corresponding to the preset gear ratios for different input rotational speeds and different oil temperatures for an unloaded gearbox

Figure 9 presents plane cross-sections of the constant gear ratio, which shows that for an unloaded gearbox, the gear ratio approximately depends only on the pressure ratio. Diagram shift shown in Figure 9 results from the operation of the spring located in the chamber of the output pulley actuator, shown in the diagram in Figure 1.

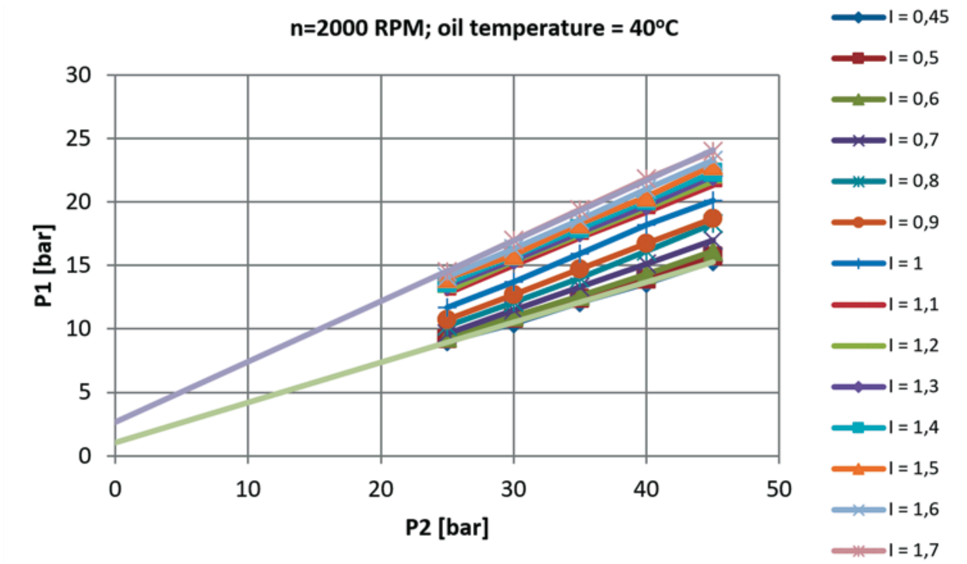

Fig. 9. Overview of pairs of pressure corresponding to preset gear ratios for different input rotational speeds and different oil temperatures for an unloaded gearbox

The last stage of the study was to check the effect of the torque transmitted through the gearbox on the process of generating the specified gear ratio.

$$P1 = f(i_{CVT}, P2, M_{input}) \quad (6)$$

where: M_{input} – Input torque

Tests were performed for the constant pressure P2 = 40 bar (minimal risk of slippage) with the input speed of n = 2000 RPM and the oil temperature T = 40 °C. The results are presented in Figure 10.

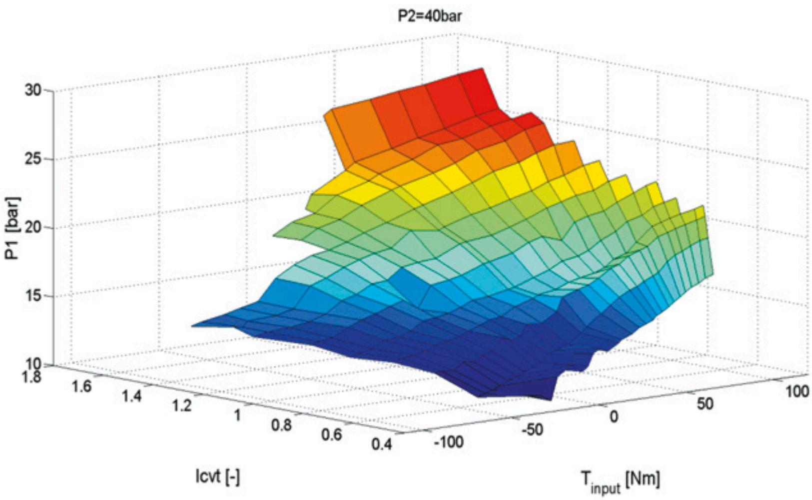

Fig. 10. The effect of the input torque on the implementation of the variator gear ratio for P2 = 40bar

From the diagram shown in Figure 10 it can be seen that the input torque influences pressures needed to implement the gear ratios. The greater the torque, the greater the pressure required for the input drive pulley necessary to achieve the same predetermined ratio.

5. Summary

1. It was decided that in the hydraulic system used by Nissan the maximum pressure of the entire hydraulic system was the variable pressure of the output pulley actuator – P2. This decision was related to the fact that the force causing the belt tension was maintained on the output pulley. To realize such an arrangement, a surface about twice smaller than the input wheel was used in the output pulley actuator, therefore producing greater pressure acting upon the surface.

2. The tests indicated limitations of the tested transmission unit and provided information about the need to change, either in the slide gate valve, or the pump, in order to retain the ability to control the system in critical areas. These areas involve very high oil temperatures at low speeds.

3. Control of solenoid valves using the average current is more convenient because of the ability to override the effect of oil temperature on pressure control process.

4. Effect of the transmitted torque on the process of generating the gear ratio by the continuously variable transmission indicates the need for deeper analysis of this phenomenon both in analytical and experimental aspects.

5. From the point of view of reducing power consumption by additional devices, such as, for example, the oil pump, it is reasonable to look for the minimum pressure that implements the preset gear ratio for a given input torque while allowing for the operation without belt slippage.

6. The experience and insights gained by the analysis of the electro-hydraulic block were used in the design of a prototype passenger car drive system.

7. The performed analysis will be used in designing a model simulating the tested transmission for testing algorithms that control the drive system of a hybrid car.

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