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NUMERICAL SIMULATION OF THE DYNAMIC BEHAVIOUR OF A MULTIFUNCTIONAL MOTOR VEHICLE EQUIPPED WITH A PRIMARY ADJUSTMENT HYDROSTATIC TRANSMISSION

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Abstract: The article analyses the solution of implementing a hydrostatic transmission in the kinematic chain of a mechanical transmission of a multifunctional motor vehicle. In this regard, the request came from a company activating in road maintenance, to develop a special transmission that allows achieving low speeds during working operations with increased torque and minimal wear of mechanical transmission. The product is developed under a research project between a company and INOE 2000–IHP, an institute specialized in hydraulic and pneumatic drives. There are presented: the construction and operation of the transmission, its scheme and structure and the numerical simulation of the main functional parameters of the multifunctional motor vehicle.
Keywords: hydrostatic transmission, closed circuit, technological speed, multifunctional motor vehicle

1. INTRODUCTION

Multifunctional vehicles are trucks where technological equipment is implemented to carry out road–related works such as snow removal, scrapping, sweeping and sprinkling of streets, mowing of public roads, or dressing trees. Multifunctional motor vehicles have two working modes.

- Marching mode – the vehicles move quickly, from one location to another. Engine torque is small and the travel speed is high.
- Technological mode – the vehicle is moving at a low speed (maximum 5 km / h) imposed by the equipment technology attached to the truck. The torque on the motor wheels is high and the travel speed is small. The traditional mechanical transmission (gearbox, cardan coupling, and differential) is effective in fast–moving (high speed) but cannot achieve and maintain low travel speeds. To achieve and maintain a low travel speed with an increased torque on the wheel there is used a hydrostatic transmission, which, besides high power density, also offers increased mobility. Practically the vehicle has two types of independent transmission: mechanical and hydrostatic. Switching from one transmission to the other is done by simply switching a button. Mechanical transmission is used in marching mode, i.e. high–speed travel mode and hydrostatic transmission – in "technological mode". Electronic control of the hydrostatic transmission ensures a smooth start with a continuous speed control and safe braking.

2. MATERIAL AND METHOD

≡ Construction and operation of hydrostatic transmission

The constructive and functional scheme of hydrostatic transmission is shown in Figure 1. In Figure 1.a one can notice that in the case of mechanical transmission, the torque supplied by the MT motor is transmitted to the RM drive motors via the CV gearbox, the AC shaft and the DF differential (2). Implementation of hydrostatic transmission is achieved by introducing the MH hydraulic motor into the kinematic chain of the mechanical transmission, as shown in Figure 1.b, the PH pump being driven from the power outlet of the MT motor.

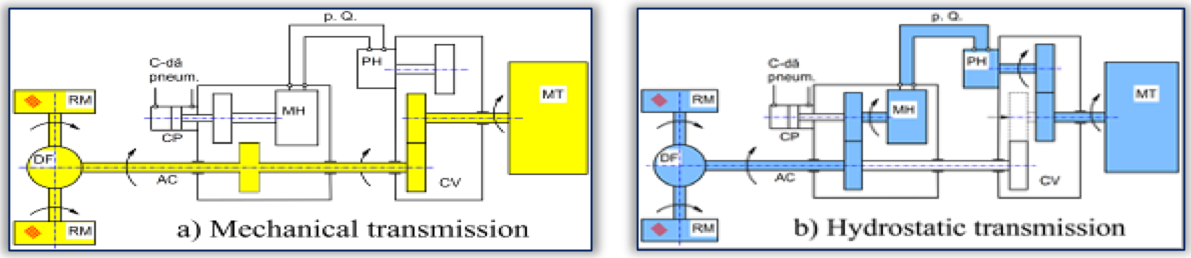


Figure1 – Constructive and functional hydrostatic transmission scheme

Connecting or disconnecting the MH hydraulic motor from the AC shaft is carried out with the pneumatic cylinder CP powered by the compressed air network of the vehicle. The hydraulic PH pump is driven from the power outlet of the truck directly or via a cardan shaft.

Activating the hydrostatic transmission is done as follows (figure 1b):

- change the CV gearbox to neutral to deactivate the mechanical transmission. This disengages the MT motor from the AC shaft;

— the power take–off for the pump PH is coupled. This engage the hydraulic motor MH with the AC shaft with the pneumatic cylinder CP.

The kinematic chain of the hydrostatic drive has two branches:

- hydraulic power generation kinematic chain: MT–CV–PH;
- hydraulic power use kinematic chain: MH–AC–DF–RM.

The energy flow of the hydrostatic transmission undergoes two energy conversions:

- the hydraulic pump PH converts the mechanical power (torque x speed) received from the MT motor via the CV gearbox in hydraulic power (pressure x flow) which it transfers to the hydraulic engine MH;
- the hydrostatic MH converts the hydraulic power received from the PH pump into mechanical power (torque x speed) which it transfers to the drive wheels via the AC shaft and the DF differential.

≡ Diagram and structure of hydrostatic transmission

The hydrostatic transmission shown in Figure 2 consists mainly of: hydrostatic pump 1, hydrostatic motor 2 and refreshment (vent) valve 3 (3). These components together form a closed hydraulic circuit (1).

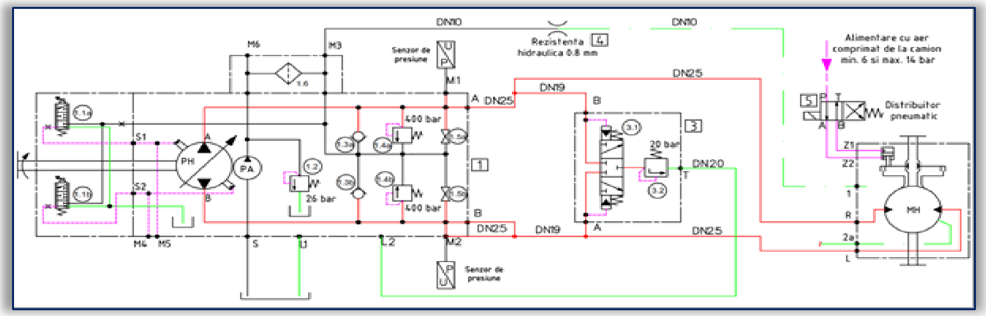


Figure 2 – Constructive and functional hydrostatic transmission scheme

The main PH pump supplies hydraulic power to the MH engine. (5) The PA auxiliary pump compensates for the internal losses of the two hydraulic machines and introduces cooled and filtered oil into the closed hydraulic circuit. Reversing the discharge direction and changing the flow rate of the PH pump is achieved by proportional electric valves 1.1.a and 1.1.b. The safety valve 1.2 protects the PA overpressure pump. The sensing valves 1.3.a and 1.3.b direct the flow rate of the PA pump into the low pressure branch of the closed circuit. The pressure valves 1.4.a and 1.4.b protect against overpressure the two branches A and B of the closed circuit. The 1.5.a and 1.5.b valves open when the truck is towed and the MH hydromotor becomes a pump.

Filter 1.6 ensures filtering of oil pumped into the system. The valve 3.1 removes an oil quantity (about 10% of the PH pump flow) from the low–pressure branch of the closed circuit that comes from the hydromotor. The extracted oil is replaced with "fresh" oil supplied by the PA pump through the filter 1.6 and the sensing valves 1.3.a or 1.3.b. Pressure valve 3.2 maintains a pressure of approx. 20 bar on the closed circuit low pressure branch. Part of the flow rate of the PA pump is routed through the resistor 4 to the MH hydromotor in order to lubricate and cool it in the fast movement phase.

The pressure sensors transmit information to the electronic controller of the transmission. The pneumatic valve 5 connects / disconnects the MH hydromotor from the cardan shaft.

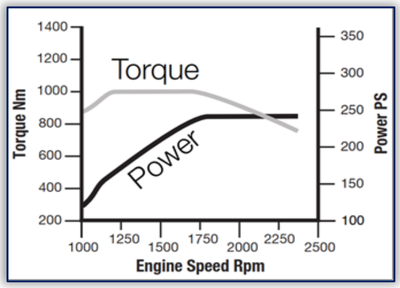


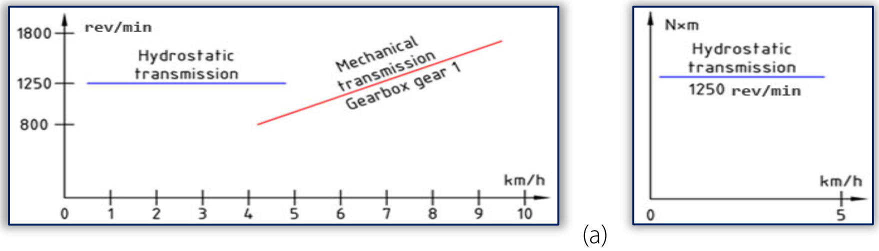
Figure 3 – Torque, power and speed diagram of the thermal motor (11)

≡ Energy efficiency in the technological mode

The thermal motors fitted to multifunctional motor vehicles operate at maximum efficiency in the speed range of 1200 to 1800 rpm, as shown in Figure 3. In the maximum efficiency range the torque developed by the engine is constant; using the thermal engine at speeds below 1200 rpm. The ratio of power / torque supplied and the fuel consumption is maximum. i.e. its maximum energy efficiency.

In order to achieve the very low travel speeds required by the technological needs of multifunctional equipment, one needs to remove the thermal engine from the working range with maximum efficiency.

Hydrostatic transmission offers what the mechanical transmission cannot accomplish: low travel speeds with the thermal engine operating in the maximum efficiency range. This can be seen from the diagrams shown in Figure 4. It results from this figure that the hydrostatic transmission ensures that the vehicle is driven at very low speeds (0.5 ÷ 5 km / h) at an engine speed of 1250 rpm located in the maximum efficiency range (4). The mechanical transmission cannot achieve low travel speeds in the efficient running range of the thermal engine.



(a) (b)

Figure 4 – Comparative diagrams: mechanical transmission – hydrostatic transmission
a) Velocity and speed diagram; b) Speed and torque diagram

≡ Numerical simulation of the main parameters of hydrostatic transmission

The numerical simulation of the main parameters of the hydrostatic transmission has been performed using the AMESim simulation environment (8). The simulation scheme is shown in Figure 5.

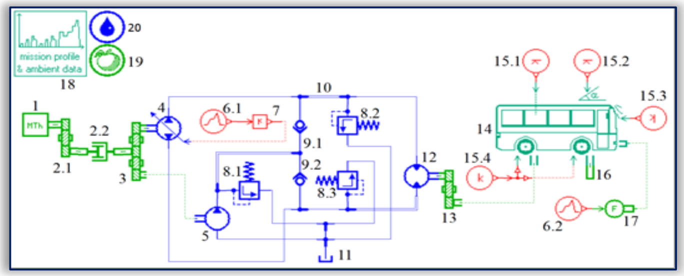


Table 1. The main parameters of the simulation:

Thermal engine	1250 rpm / 1000 Nm
Variable flow pump	75 cc/rev
Hydrostatic engine	1000 cc/rev
PTO	1524 rpm / max 600 Nm
Compensation pump	1 cc/rev
The weight of the loaded vehicle	18 t

Figure 5 – Simulation scheme: 1. Thermal engine; 2.1 Mechanical speed reducer; 2.2 Elastic couplings; 3. Mechanical node. 4. Variable flow pump. 5. Compensation pump; 6. User–defined signal source; 7. Gain; 11. Hydraulic tank; 12. Hydraulic motor; 13. Mechanical speed reducer; 14. Variable load vehicle without slip; 15. Constant signal source; 16. Zero torque source; 17. Conversion of signal input into a force [N]; 18. Mission profile and ambient data.

3. RESULTS

The goal of hydrostatic transmission implementation is to achieve travel speeds of values between 0.5 and 5 km / h. The charts resulting from numerical simulation are shown in Figure 6. They show the evolution of the main parameters and the dynamic behaviour of the multifunctional motor vehicle.

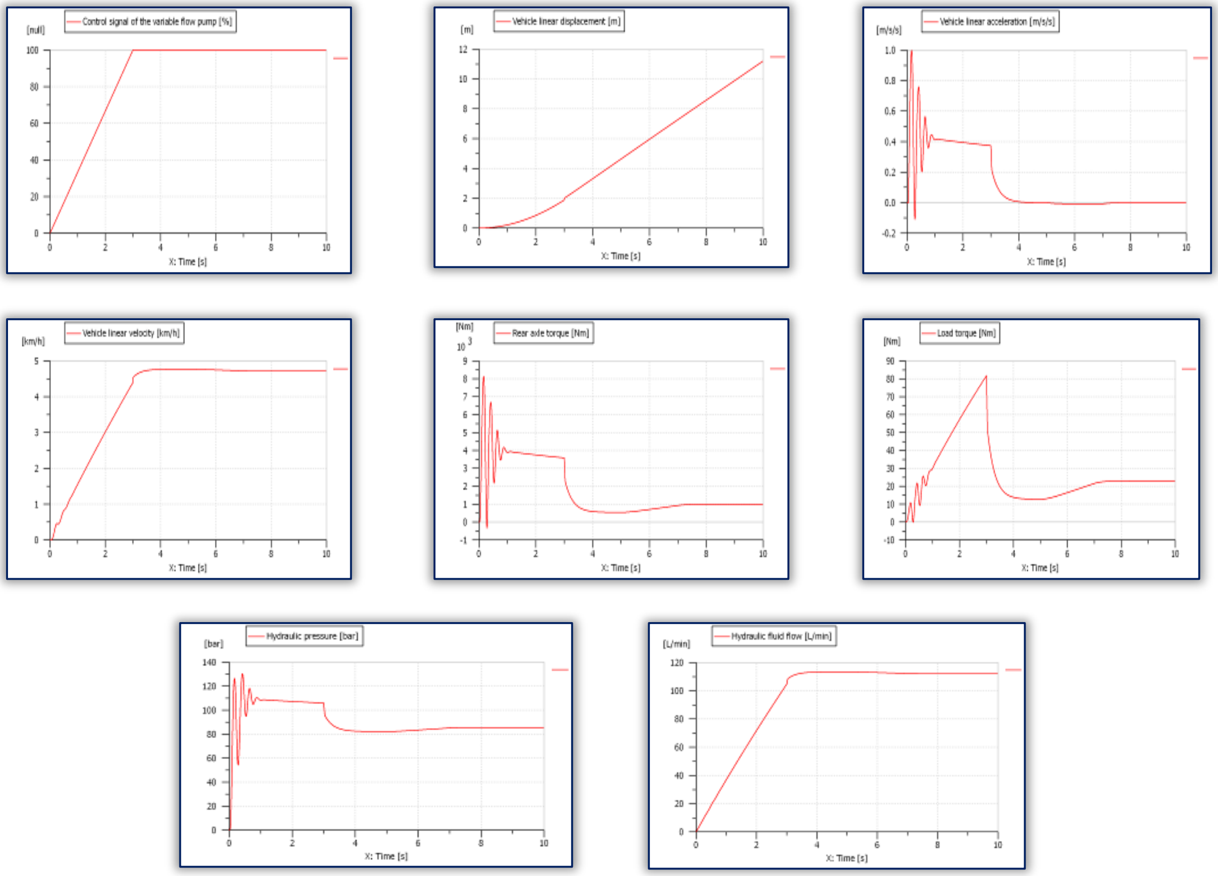


Figure 6 – Variation of the main parameters of the simulated system

Figure 6 shows the response of the system to the ramp signal. For the start the displacement occurs slowly and becomes stable at a constant speed of 4.8 km / h. In the first phase, there is a variation in the acceleration which is rapidly attenuated, having small amplitude relative to the mean value. The other parameters do not exceed the limit values.

After obtaining the physical model and testing it, the results obtained by the simulation will be compared with the experimental ones, which will lead to the validation of the simulation model.

4. CONCLUSIONS

Following the analysis of the proposed solution it can be concluded that the use of hydraulic transmission in the technological travel regime has the following advantages:

- The truck can achieve lower travel speeds than those it can achieve with mechanical transmission;
- The thermal engine operates in the maximum efficiency range even at these very low speeds.

The hydrostatic transmission ensures for the multifunctional motor vehicle operation performances that the mechanical transmission cannot achieve: very low travel speeds at the maximum energy efficiency of the thermal motor.

Confirmation of these conclusions and the results obtained by numerical simulation will be done after the physical development and testing of the hydromechanical transmission model.

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