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FOUR-WHEEL DRIVE HIGH EFFICIENCY HYBRID TRANSMISSION FOR MULTIPURPOSE MOTOR VEHICLES

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Abstract: *Multipurpose motor vehicles are trucks on which various equipment has been implemented in order to achieve works related to the road that they travel on, such as snow removal, sweeping and spraying the streets, roadside mowing, trimming trees, etc.*
Multipurpose vehicles have two operating modes. ●Marching mode. The vehicles move rapidly from one location to another. Torque at the drive wheels is small and the speed is high. ●Technological mode. The vehicle is traveling at a low speed (max. 8 km/h) imposed by the working technology of multifunctional equipment. Torque at the drive wheels is high and the speed is low. In this sense, the request came from a company in the field of road maintenance to achieve a special transmission that allows achieving low speeds during working operations. The product is made in a research project between the company and a research institute specialized in hydraulic drives.
The article analyzes the solution of increasing efficiency of multifunctional vehicles in the technological mode by using a hybrid (mechanical-hydraulic) four-wheel drive transmission achieved through the implementation of a hydrostatic transmission in the kinematic chain of the mechanical transmission. The following are presented: hybrid transmission components and functioning, hydrostatic transmission schematic diagram and structure, energy efficiency as a result of the hydraulic transmission implementation and numerical simulation of the main functional parameters of the transmission.

Keywords*: Hybrid transmission, four-wheel drive, energy efficiency, multifunctional motor vehicles*

1. Introduction

Multifunctional motor vehicles are trucks on which technological equipment is implemented, with which works generally related to roads are done such as: removing snow from the road, spreading anti-slip materials, sweeping and sprinkling streets, mowing public roads, or trimming trees etc.
These vehicles have two modes of travel: fast and slow.
In the fast-moving mode, vehicles move at high speed on the road from one location to another. The torque on the drive wheels is small and the speed is high.
In slow travel, the vehicle moves at a low speed (max. 5 km/ h) imposed by the multifunctional equipment technology. The engine torque is high and the speed is low. In this regard, a request has come from a road maintenance company for a special transmission that allows for low speeds during the work operations. The product is being developed as part of a research project between the company and an institute specialized in hydraulic drives.
Traditional mechanical transmission (gearbox, drive shaft, differential) is effective in rapid travel mode (high speed) but it is both energy and operating inefficient in the "technological speed" mode.
The mechano-hydraulic transmission [1], which is the subject of the article, adds the benefits of the two types of transmissions. Practically, the vehicle has two types of independent transmission: mechanical and hydraulic. Switching from one transmission to the other is done by a simple switching. Mechanical transmission [2] is used in marching mode, i.e. travel on high-speed road, and the hydrostatic transmission - in "technological mode". Electronic control of the hydrostatic transmission ensures smooth start, continuous speed control and safe braking.

2. Components and functioning of hybrid transmission

The constructive and functional schematic diagram of the hybrid transmission is shown in fig. 1.
In the case of mechanical transmission, the torque supplied by the MT motor is transmitted to the engine wheels (RMF and RMS) via the CV gearbox, the AC drive shaft, the CD distribution box and the front and rear axle (ACF and ACS) - see fig. 1a.

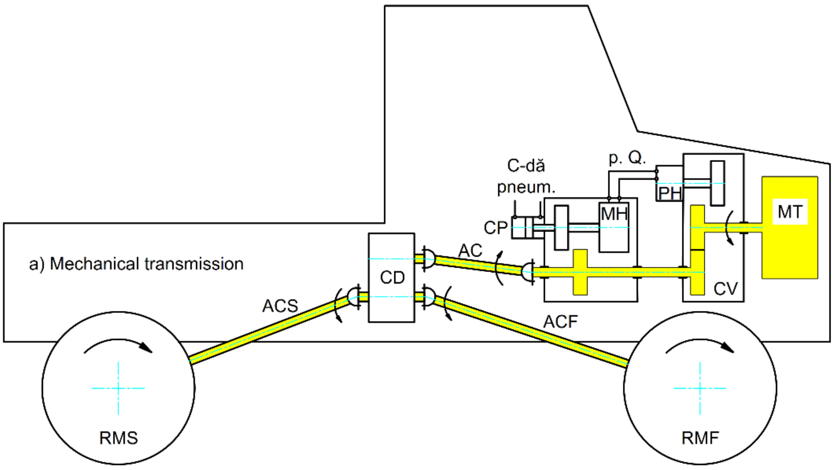


Fig. 1a. Mechanical transmission

The hydrostatic transmission is achieved by introducing the MH hydraulic motor into the kinematic chain of the mechanical transmission - see fig. 1b.

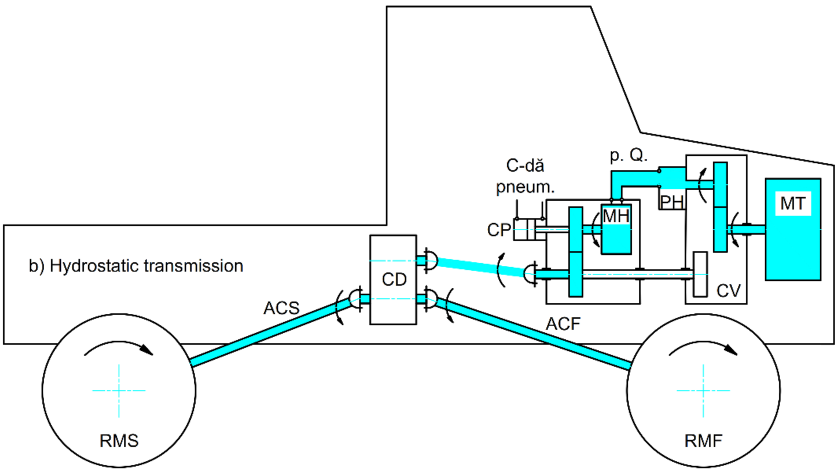


Fig. 1b. Hydrostatic transmission

MT - thermal motor; PH - hydrostatic pump; CP - pneumatic cylinder; DF - differential; CV - gearbox; MH - hydraulic motor; AC, ACS and ACF - cardan shafts; RMS and RMF - engine wheels; CD - transfer box.

Connecting or disconnecting the MH hydraulic motor from the AC shaft is done with the CP pneumatic cylinder supplied from the compressed air network of the truck.
The hydraulic PH pump is driven from the power outlet of the truck directly or via a cardan shaft.
Activation of the hydraulic transmission [3] is as follows: (see fig. 1b)
- shift the CV gearbox to neutral to deactivate the mechanical transmission.

- connect the power take-off to PH pump;
- engage the hydraulic motor MH with the AC shaft with the CP pneumatic cylinder;

The kinematic chain of the hydrostatic transmission has two branches:
- the kinematic chain of the pump composed of: MT - CV - PH;
- engine kinematic chain consisting of: MH - AC - CD - (ACS - ACF) - (RMF - RMS).

The energy flow of the hydrostatic transmission [4] undergoes two transformations:
- hydraulic pump PH converts the mechanical power (torque x speed) received from the MT motor via the CV transmission in hydraulic power (pressure x flow) which it transfers to the hydraulic motor MH;
- Hydraulic engine MH converts the hydraulic power received from the PH pump into mechanical power (Torque x speed), which it transfers to the drive wheels via AC, ACS and ACF shafts and the distribution box.

3. Schematic diagram and structure of hydrostatic transmission

The hydrostatic transmission is part of the hybrid transmission and consists mainly of: hydraulic pump 1, hydraulic motor 2 and refreshment valve 3 (see figure 2). These components together form a closed hydraulic circuit. [5]

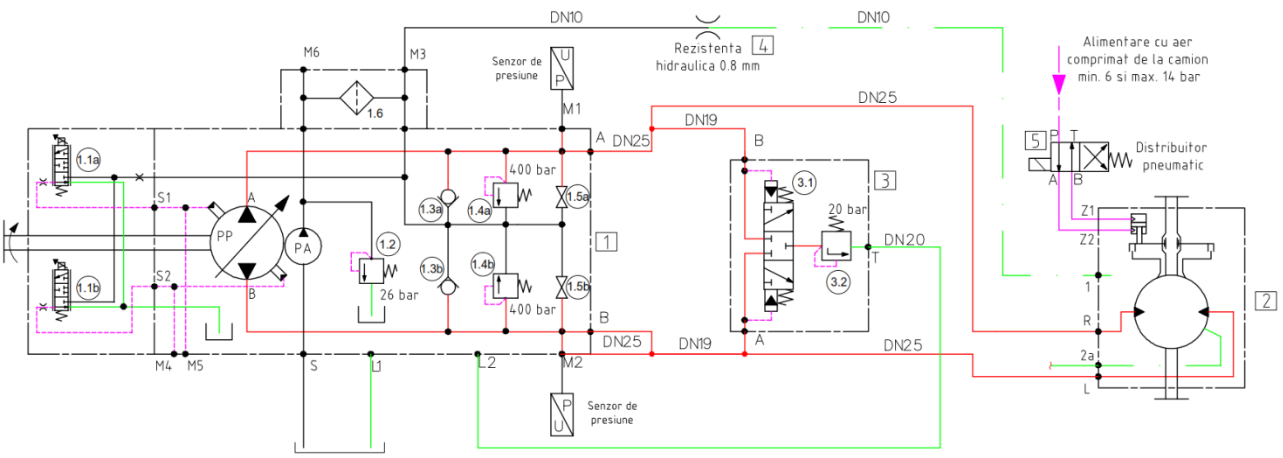


Fig. 2. Hydraulic schematic diagram of a hydrostatic transmission

Main pump PP supplies hydraulic power to the engine 2.
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 PP pump is done by proportional electrical valves 1.1.a and 1.1.b.
Safety valve 2 protects the PA overpressure pump.
The sensing valves 1.3.a and 1.3.b lead the flow rate of the PA pump into the low pressure branch of the closed circuit. [6]
The pressure valves 1.4.a and 1.4.b protect the two branches A and B of the closed circuit against overpressure. The valves 1.5.a and 1.5.b open when the truck is towed, and the hydro-motor 2 becomes a pump. Filter 1.6 ensures filtering of oil pumped into the system. The valve 3.1 removes from the low pressure branch of the closed circuit a quantity of oil (about 10% of the flow rate of the PP pump) coming from the hydro-motor. 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 hydromotor 2 in order to

lubricate and cool it in the fast displacement phase. The pressure sensors transmit information to the electronic controller of the transmission. The pneumatic valve 5 engages / disengages the hydro-motor 2 from the shaft.

4. Energy and functional efficiency of transmission

The thermal motors fitted to multifunctional vehicles operate at maximum efficiency in the speed range of 1200 to 1800 rpm, as shown in fig. 3.

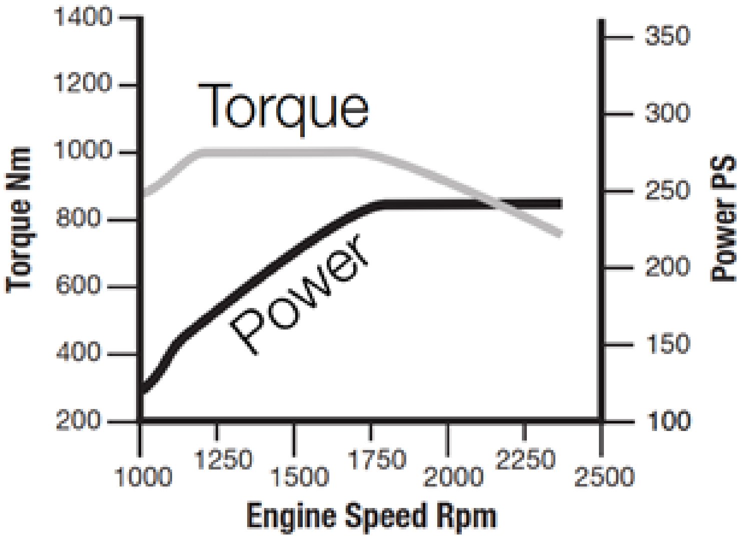
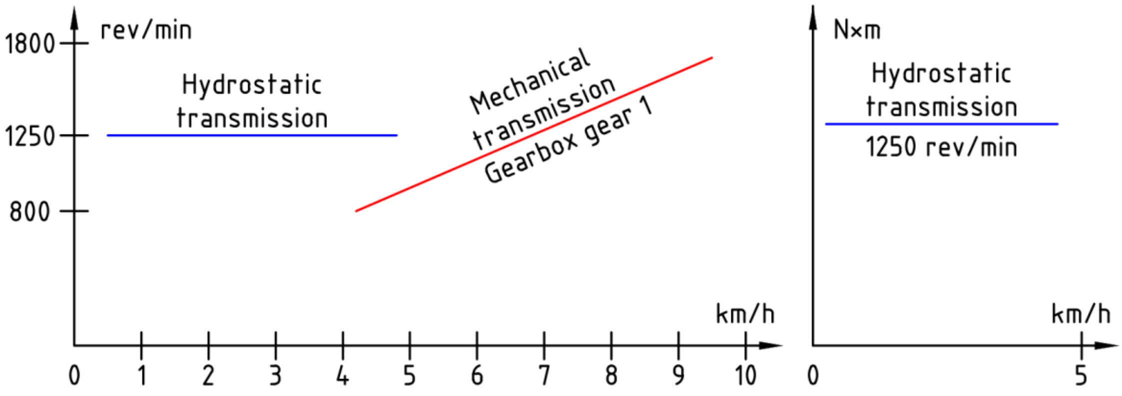


Fig. 3. Torque, power and engine speed characteristic [7]

In the maximum efficiency range, the torque developed by the engine is constant and maximum. Also, the ratio of the power / torque supplied and the fuel consumption is maximum, i.e. its energy efficiency is maximum.
Using the thermal engine at speeds below 1200 rpm: In order to achieve the very low travel speeds required by the technological needs of multifunctional equipment, one should remove the thermal engine from the working range with maximum efficiency.
Hydrostatic transmission offers what the mechanical transmission can not accomplish: low travel speeds with the thermal engine operating in the maximum efficiency range. This can be seen from the shematic diagrams shown in fig. 4.



a) velocity - speed diagram b) speed - torque diagram

Fig. 4. Comparative diagrams: mechanical vs. hydraulic transmission

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. The mechanical transmission can not achieve low travel speeds in the efficient running range of the thermal engine.

5. Numerical simulation of the multipurpose motor vehicles

The numerical simulation of the main parameters of the hydrostatic transmission has been performed using the AMESIM simulation environment [8] [9]. The simulation schematic diagram is shown in Figure 5.

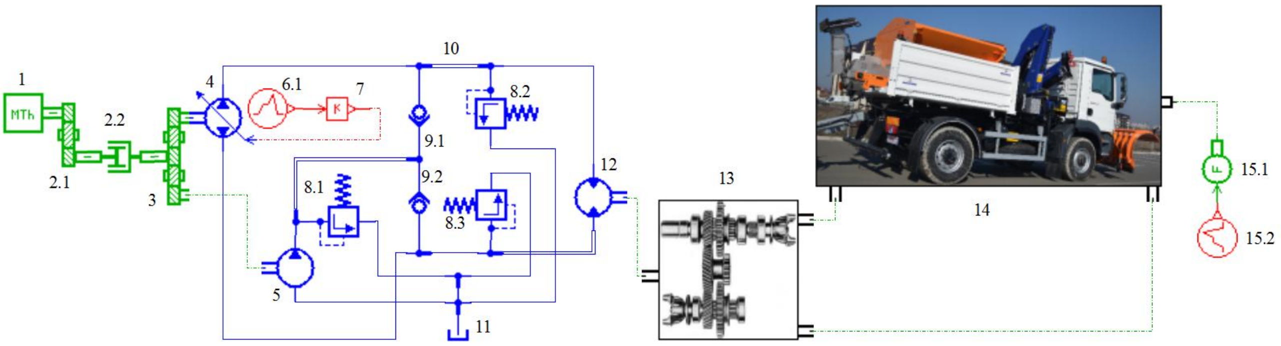


Fig. 5. Simulation schematic diagram

Table 1: Components included in the simulation schematic diagram

1 Thermal engine	8 Relief valve
2.1 Mechanical speed reducer	9 Check valve
2.2 Elastic couplings	11 Hydraulic tank
3 Mechanical node	12 Hydraulic motor
4 Variable flow pump	13 Transfer box
5 Compensation pump	14 Multifunctional motor vehicle
6.1 User-defined signal source	15.1 Conversion of signal input into a force [N]
7 Gain	15.2 User-defined signal source

The charts resulting from numerical simulation are shown in Figure 6a and Figure 6b.

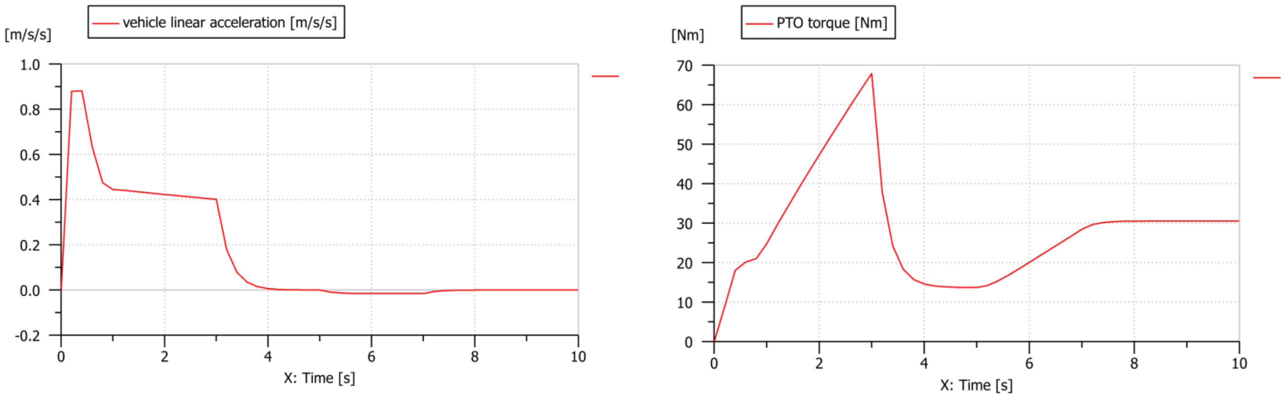


Fig. 6a. Variation of the main parameters of the simulated system

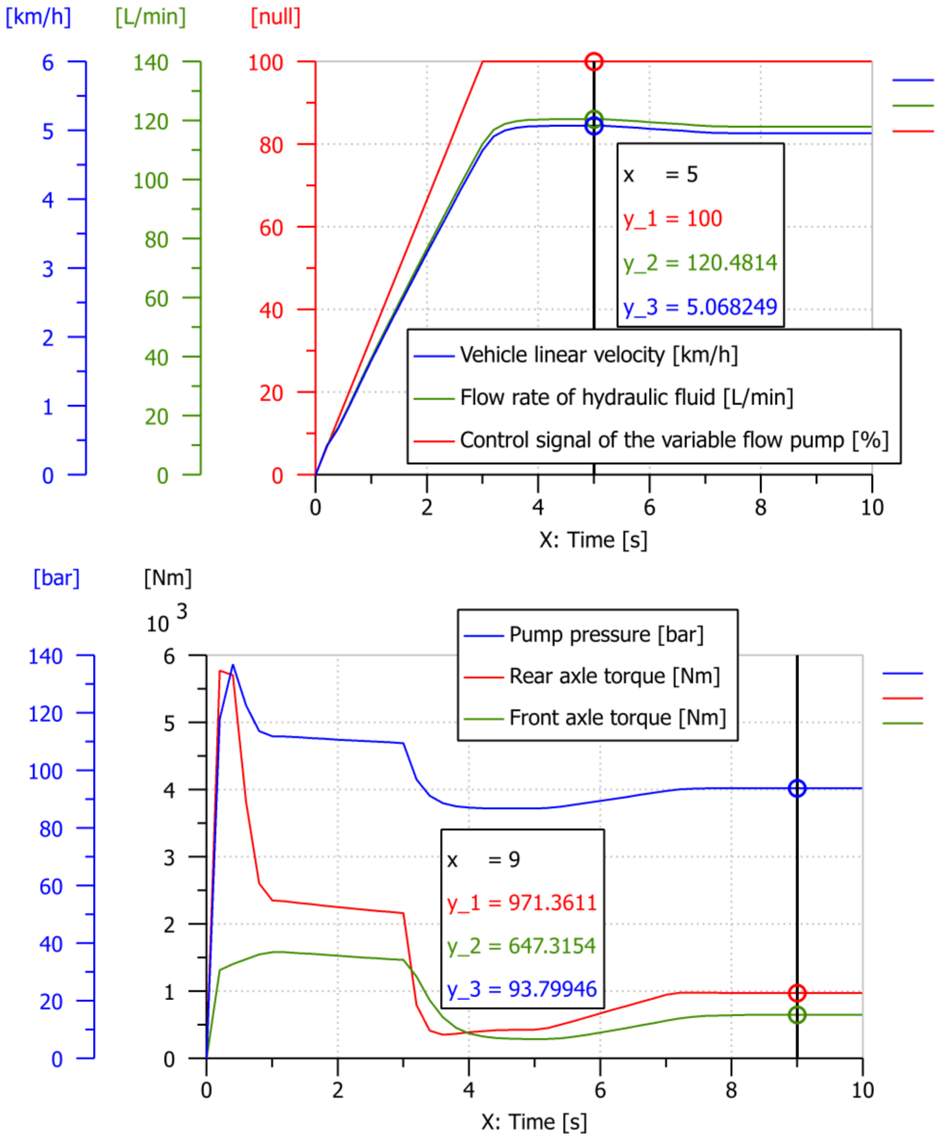


Fig. 6b. Variation of the main parameters of the simulated system

After achieving the physical model and testing it, the results obtained by simulation will be compared with the experimental ones.

6. Conclusions

For the energy efficiency of multifunctional vehicles in the very low speed technological operation mode, the article proposes the solution of the implementation of a hydraulic transmission in the kinematic chain of the truck's mechanical transmission.
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:
A) The truck can achieve lower travel speeds than those it can achieve with mechanical transmission;
B) The thermal engine operates in the maximum efficiency range even at these very low speeds.
The hydrostatic transmission ensures for the multifunctional vehicle operation performances that the mechanical transmission can not 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 hydro-mechanical transmission model.

Acknowledgments

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