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SIMULATION OF A COMBINED MECANO-HYDRAULIC DRIVE USED IN MOBILE APPLICATIONS

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Abstract: *The presented paper addresses the problem of low speeds and high torques. More concretely it is about the analysis of one product in particular, namely the Combined Mechanico-Hydraulic Drive. This drive permits a vehicle of moving in one of two modes: transit mode, where the movement is transmitted as is from the vehicle's engine and work mode where it moves with a constant low speed by means of a hydrostatic transmission. To get more insight into the operation of this device, some simulations were made.*

Key words: *low speed, combined drive, hydrostatic drive, high torque, multi-variable simulation*

1. INTRODUCTION

Low speeds and high torques have always been a challenge for engineers. Most commonly these types of problems are addressed with hydraulic solutions.

Compared to mechanical transmissions, hydraulic drives have certain advantages like:

- High stability at low speeds;
- They have a simple design and are easy to install;
- The prime mover's power is used in an optimal way;
- The equipment on which they are installed adapts with ease to external conditions;
- A hydraulic transmission lowers fuel consumption and reduces overheating;
- The position of the hydraulic motor is independent of the prime mover's position, making equipment design much more simpler;
- The transmission fluid acts as lubricant as well;

But, like any other technology, hydraulic drives have their limitations:

- They are more expensive then mechanical solutions because of the additional control, filtering, safety and other equipment needed;
- They have a lower efficiency than mechanical drives, no more than 80% as opposed to 92%;
- In case of damage the fluid can pollute the environment;
- In some cases there's a fire hazard because of the nature of fluid used;
- Contamination of the fluid can lead to equipment wear.

2. THE COMBINED MECHANO-HYDRAULIC DRIVE

There are some mechanical solutions like those presented in the patents DE1816069, IT01277770, US5826460, and US 6393944. These make use of gears, couplings and clutches. The disadvantage of these solutions is the complex kinematics and the resulting discrete speeds. The analyzed product wants to solve this problem by means of hydraulic components and by producing a continuously variable output speed [1].

The Combined Mechano-Hydraulic Drive (CMHD) was designed for a specific application where a high load vehicle needed to be moved with very low speeds in accordance with specific requirements. It would be placed between the vehicle's own gear box and the rear axle (the driving axle). This way the vehicle can move in one of two modes. The first mode is transit mode. In transit mode the vehicle works just lake any regular vehicle, within the speed range indicated by the vehicle manufacturer. The second mode is work mode. This is the mode in which the vehicle is put into second gear and by means of the hydraulic transmission in the CMHD outputs speeds of up to 2 m/s.

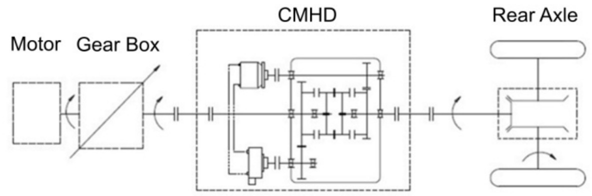

Fig. 1. The CMHD set in transit mode.

In transit mode the movement is transferred inside the CMHD by means of a frontal coupling that connects the input shaft to the output shaft directly (Fig. 1.).

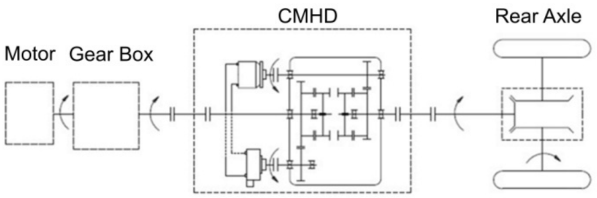

Fig. 2. The CMHD set in work mode

In work mode the frontal coupling is uncoupled and the input shaft transfers the motion to a gear which in turn drives a variable displacement pump. The pump creates a flow of oil and drives a fixed displacement hydraulic motor. The output shaft of the motor is connected to an output gear that sets the rear axle into motion (Fig. 2.).

3. THE COMPONENTS OF THE CMHD

3.1. The hydrostatic circuit

The main focus of the research is the hydrostatic circuit in this transmission. The reason for this is that the mechanical part has the function of either transmitting the movement unaltered or to ensure an appropriate input and output speeds for the hydrostatic circuit to do its part. The latter is done by means of two gears. The input gear has a ratio of 2,0625 and the output one a ration of 5,86.

As a result, we will follow the processes that take place in this hydraulic part.

Like any other hydrostatic circuit, this one is composed of a variable displacement hydraulic pump and a fixed displacement hidromotor, making it a primarily driven transmission.

The circuit also has pressure release valves to ensure a safe operation and a discrete directional valve to be able to reverse the direction of movement.

3.2. The variable displacement pump

The chosen pump is a Parker PV-023-L-1-K-1-T-1-N-UPK. This means that it has a geometric volume of 23 cm^3/rot. and has a UPK controller. The controller is presented in Figure 3. By means of this controller the user can adjust the flow as well as the pressure in the system.[2]

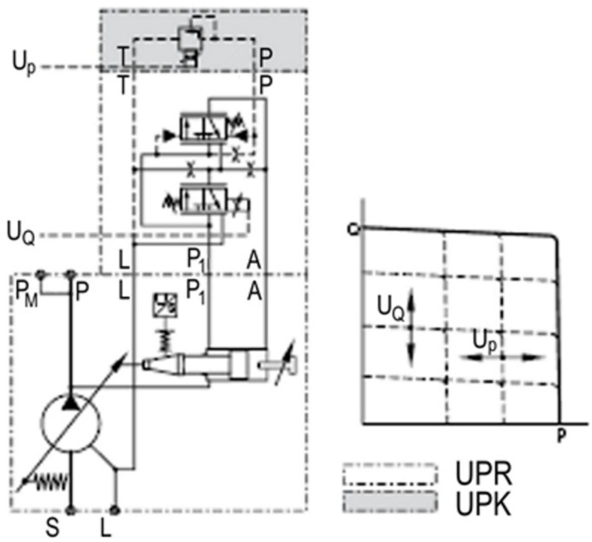

Fig. 3. The controller for the PV-023 pump [2]

Other parameters to be taken into account are the maximum pressure of 420 bar, the maximum speed of 3000 min^{-1} and the flow at 1500 min^{-1} of 34,5 L/min. [2]

3.3. The fixed displacement motor

The chosen hidromotor is a Parker F12-030-MS-TV-T-000-000-0 bent axis piston motor. It has a geometric volume of 30 cm^3/rot, a maximum pressure of 480 bar. The maximum continuous rotation speed of 5600 min^{-1} ensures a maximum continuous flow of 168 L/min. The bent axis angle is 40 degrees. [3]

4. SIMULATION OF THE COMBINED MECHANO-HYDRAULIC DRIVE

The simulations were done using a program called AMESim Rev 10, used for modeling and analysis of uni-dimensional systems [15-ref3]. It uses a multi-port approach which permits the transmission of information about energy exchanges between components [18-ref3]. The software uses the DASSL (Differential Algebraic System Solver) algorithm for solving differential algebraic equations and the LSODA (a combination of Adams code and the Gear method) algorithm for ordinary differential equations.[5][6]

The uni-dimensional model of the CMHD is presented in Figure 4. The motion from the prime mover (1) is transferred to the input gear (2) which sets in motion the pump (3). The pump outputs a flow, set by the pumps controller, through the flexible hose (4) to the fixed displacement hydraulic motor (5). The output shaft of the motor is connected to the second gear of the CMHD (6) which transfers the motion to the differential of the rear axle (7). Besides the vehicle parameters (8) we have to take into account the friction with the road (9) and the inclination (10). For measuring the rotation speed of the shafts at different positions, virtual rotation sensors are used (11, 12, 13).

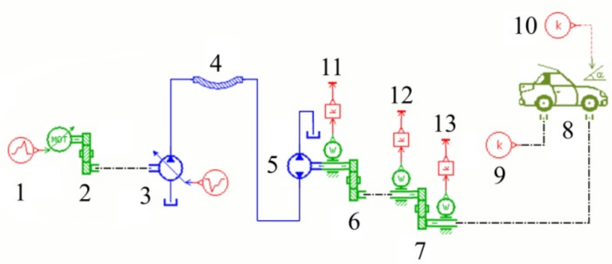

Fig. 4. Simulation model of the CMHD

For calculating the friction with the road surface, the following formula was used:

$$F_R = \left(k_{conc} + \sin\left(\alpha \cdot \frac{\pi}{180}\right)\right) \cdot m_v \cdot g \qquad (4.1.)$$

where:

k_{conc} – [-] friction coefficient for concrete roads;

α – [deg] road inclination;

m_v – [kg] vehicle mass;

g – [m/s^2] gravitational acceleration.

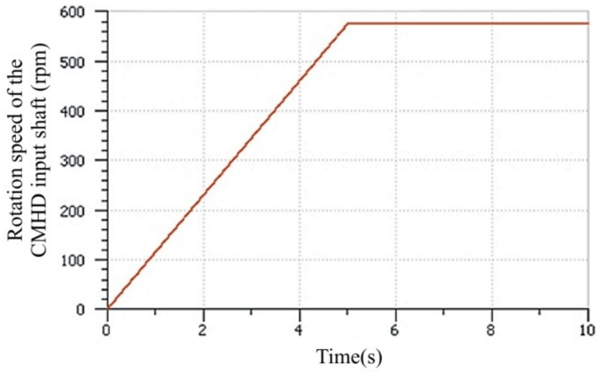

Fig. 5. Rotation speed of the input shaft

To be able to output the required torque during the work phase, the vehicle engine must supply the maximum torque. In the case of the of the Mercedes Sprinter 510 CDI the maximum torque is achieved between 1500 and 2400 min^{-1}. The vehicle is set into second gear ensuring an input speed at the CMHD shaft of 575 min^{-1}, as shown in Figure 5. The speed increases steadily from zero to the required speed in about 5 seconds.

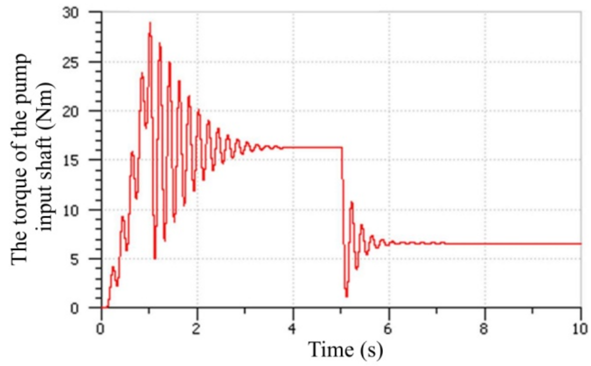

Fig. 6. Torque of the pump shaft

In contrast to the lean increase of the speed, the torque variation is much more fluctuant. As Figure 6 shows, the torque increases in steps up to a maximum value of about 29 Nm. After this initial shock, due to vehicle's inertia, the torque becomes stable as the variations are dampened. There's a final shock as the vehicle reaches the work speed.

At the other end of the transmission the output speed is transferred to the rear axle differential and finally to the wheels. The vehicle speed varies similar to the input speed, as shown in Figure 7. The working speed of 1,1 m/s is reached in 5 seconds, as imposed by the required regime entry distance of three meters.

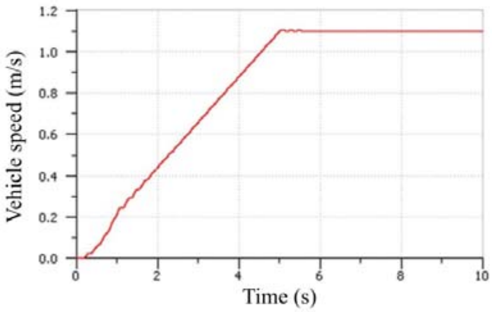

Fig. 7. Vehicle speed.

The output torque necessary for moving the vehicle is calculated with the formula [8]:

$$M_t = \frac{F_{R0} \cdot r}{i_{tr} \cdot \eta_{tr}} \quad (4.2)$$

$$M_t = \frac{13589{,}636 \cdot 0{,}32}{10{,}732 \cdot 0{,}63} = 643{,}181\ [Nm] \quad (4.3)$$

where:

F_{R0} - the traction force needed to overcome the sum of all resistances (air, ramp, friction with the road, inertia);

r - the radius of the vehicle's wheels;

i_{tr} - the total transmission ratio of the vehicle's transmission system (including the CMHD);

η_{tr} - the (estimated) efficiency of the vehicle's transmission system.

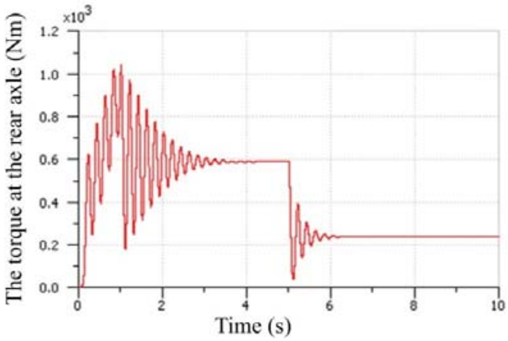

Fig. 8. The torque at the rear axle.

As shown in Figure 8, the torque jumps to a value close to the theoretical one and after overcoming the inertia of the system, it settles down at a lower value of about 250 Nm.

We can observe similar behavior in the output torque as in the input torque.

5. CONCLUSIONS

The Combined Mechano-Hydraulic Drive is a solution for the proposed problem. The initial simulations done on a one dimensional model shows the behavior of this device given certain work parameters. Further testing is needed for comparison with the simulation results.

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Simularea unui Grup Combinat de Acționare folosit în aplicații mobile

Prezenta lucrare adresează problema vitezelor mici şi momentelor mari. Mai concret, analizează un produs în particular şi anume Grupul Combinat de Acționare Mecano-Hidraulic. Această transmisie permite deplasarea în unul din două moduri: tranzit, caz în care mişcarea se transmite nealterată de la cutia de viteze a vehiculului şi modul de lucru în care se deplasează constant cu o viteză scăzută prin intermediul unei transmisii hidrostatice. Pentru a pătrunde în adâncul fenomenelor ce apar în timpul funcționării acesteia, s-au realizat anumite simulări.

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