



Constructive Influences of the Energy Recovery System in the Vehicle Dampers

Vlad Serbanescu, Horia Abaitancei, Gheorghe-Alexandru Radu, Sebastian Radu
Transilvania University Brasov
B-dul Eroilor nr. 29, 500036, Brasov, Romania
v.serbanescu@yahoo.com, h.abaitancei@unitbv.ro, radugal@unitbv.ro, s.radu@unitbv.ro

ABSTRACT

An alternative solution to the today classic propulsion represents the hydraulic hybrid solution. The present work is a study regarding the integration of a hydraulic hybrid system of recovery of energy dissipated in the damping system of the vehicle. For the pre-dimensioning of this recovery system are used dynamic parameters of an experimental vehicle type IMS M461, which rolls on an uneven path. The virtual simulation of the system was realized with the help of AMESim 8.0 software. The objective of our current research is to identify all the parameters that influence the energy recovery system, these include: the supply with energy, the stiffness of the tiers, amplitudes and frequencies inducted by the road profile and recovery cylinder diameter. The implementation of the system can represent a significant reduction of energy required during the vehicle functioning regime.

INTRODUCTION

Today the industry of vehicles has developed a major concern about the mass reduction of the pollution, consumption and fossil fuels use. A solution represents the alternative propulsion systems.

A developing direction is the hydraulic hybrid solution, due to the density of the transmission power through fluids. The program EPA – Ford – Eaton – UPS has demonstrated the efficiency of the hydraulic hybrid solution, considered to be the hybrid solution with the best cost-efficiency ratio.

For the pre-dimensioning of this recovery system are used dynamic parameters of an experimental vehicle type IMS M461, old-timer off-road, with simple construction and can be easily modified, which rolls on an uneven path. From a dynamic point of view, the vehicle is a sprung mass in vertical movement due to the unevenness rolling path and the functioning regimes. This movement is considered as a source of energy for the hydrostatic propulsion system.

The simulations were realized with the help of the AMESim 8.0 software and had the next objectives:

- The identification of the way in which the energy recovery system from the dampers realize the supply of the hydraulic hybrid transmission with traction energy.
- The identification of the influence of the vertical stiffness of different tires.
- The identification of the influence of different amplitudes and frequencies inducted by the road profile.
- The identification of the influence of the recovery cylinder diameter.

For simulation, there were used the technical characteristics of three tiers: 243 000N/m Dunlop SP Sport, 322 000N/m Bridgestone Turanza RFT and 874 000N/m Michelin Radial 11R22.5 XZA for observing the influence of the vertical stiffness coefficient [1]. As well three hydraulic cylinders with different diameters were used for energy recovery having as role the translation mechanical energy absorption due to the road profile (force x velocity) and the transformation of the hydrostatic energy.

VIRTUAL MODEL OF THE ENERGY RECOVERY SYSTEM

AMESim stands for Advanced Modeling Environment for performing Simulations of engineering systems. It is based on an intuitive graphical interface in which the system is displayed throughout the simulation process.

AMESim uses symbols to represent individual components within the system which are either:

- based on the standard symbols used in the engineering field such as ISO symbols for hydraulic components or block diagram symbols for control systems;

or when no such standard symbols exist

- symbols which give an easily recognizable pictorial representation of the system.

Using AMESim you build sketches of engineering systems by adding symbols or icons to a drawing area. When the sketch is complete, a simulation of the system proceeds in the following stages:

- Mathematical descriptions of components are associated with the icons.
- The features of the components are set.
- A simulation run is initiated
- Graphs are plotted to interpret the system behavior [2].

Further the paper presents the mathematic module of two symbols, one from the hydraulic library and one from the IPF drive:

1. MO001 – hydraulic motor

When the motor is rotated backwards, the port that is nominally the outlet (port 1) becomes the inlet. Under these conditions the pressure at port 1 is used in determining the flow rate. To avoid a discontinuity, a smooth switch between the pressures is used. The parameter 'typical speed of motor' (wtyp) is used to determine the speed range over which the transmission is made. The switching between the two pressures is assumed to take place between speeds + and - wtyp/1000 [2].

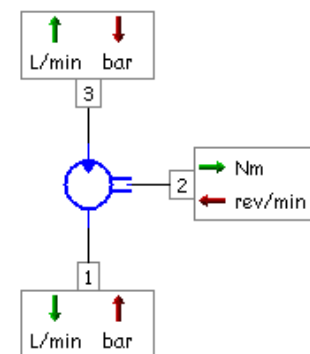


Figure 1: Hydraulic motor

Equations [2]:

The nominal flow from the motor is:

$$q_{nom} = \frac{displ \cdot speed}{1000} \text{ L/min} \quad (1)$$

The reference pressure press is taken as a linear combination of pin and pout:

$$press = (fact \cdot pin + (1 - fact) \cdot pout) \cdot 10^5 \text{ Pa} \quad (2)$$

the fact coefficient is between 0 and 1.

The fact coefficient is calculated as:

$$fact = \frac{\tanh\left(\frac{speed \cdot 1000}{wtyp} + 1\right)}{2} \quad null \quad (3)$$

The output flow rate is then:

$$qout = qnom \frac{\rho(press)}{\rho(0)} \quad (4)$$

2. TRVEH0B – vehicle load (wheels included) with Cx air penetration coefficient

TRVEH0B is a simple dynamic sub model of a vehicle load used to calculate the longitudinal acceleration, velocity and displacement of the car body. There is provision for viscous friction, road slope in percent and computation of the air resistance. There is no mass transfer during acceleration and braking that can change the vertical load. That is to say the car body model is a 1D model.

The dimensionless signal input at port 1 is interpreted as the road slope in percent (100 % = 45 deg).

A torque in Nm is input at each axle and the rotary speed in rev/min is output at both these ports. The wheel friction is modeled with a viscous friction function of the vehicle speed and a constant rolling friction.

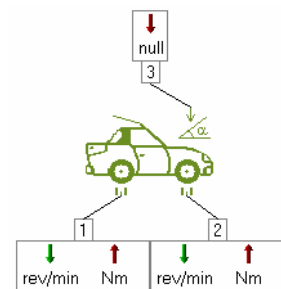


Figure 2: Vehicle

Equations [2].:

The acceleration is calculated from the four longitudinal tyre forces, the "slope force", the friction force and the aerodynamic force :

$$F_{engine} = (twhe1 / radrw) + (twhe2 / radfw) \quad (6)$$

$$F_{slope} = M_{car} \cdot g \cdot \sin(\arctan(\alpha_{slope} / 100)) \quad (7)$$

$$F_{aero} = \frac{1}{2} C_x \cdot \rho_{air} \cdot A_{vehicle} \cdot V_{vehicle} + V_{air}^2 \quad (8)$$

The sum of all the forces (resistive and torques) is divided by the body mass to have the body acceleration that will be integrated to have the velocity and the position [3].

$$amtv = \frac{F_{engine} \cdot F_{aero} + F_{slope} + F_{friction}}{M_{vehi}} \quad (9)$$

Using the two symbols mentioned and other symbols from the AMESim 4.2.0 and AMESim 8.0B software library the virtual model of the energy recovery system was modeled. This model is shown in Figure 3. The upper part of the model represents the hydraulic recovery system, while the side lower part simulates the vehicle components, like car dampers, car mass, etc. To the model are induced real road conditions with the help of frequency generators. The next subchapter presents the simulations and the results.

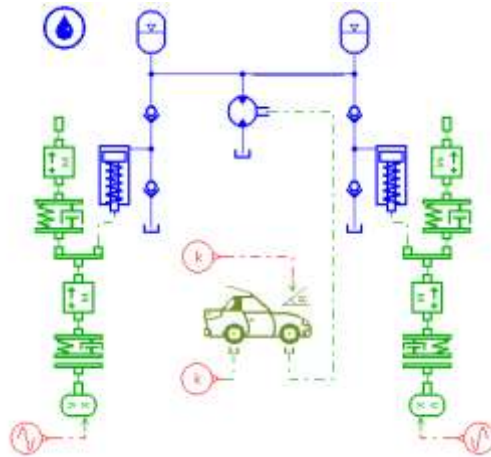


Figure 3: The AMESim model of the energy recovery system

THE VIRTUAL SIMULATION OF THE MODEL

The aim of the work is to study the different influences of the recovery cycle. Tests were conducted which should demonstrate the displacement capacity of the vehicle with hybrid-hydraulic propulsion system. As input data used for the simulations are presented in Table 1.

First it is studied the influence of the vertical stiffness of three different tires: with 243 000N/m Dunlop SP Sport; 322 000N/m Bridgestone Turanza RFT; 874 000N/m Michelin Radial 11R22.5 XZA [1]. The simulation lasted for 800 seconds on an uneven road and the frequency induced by the rolling path is of 30 Hz and the average amplitude is 5mm. The results of the simulations are presented next in Figures 4...7. The four main parameters presented are: recovered speed (see Figure 4), installation pressure (see Figure 5), outlet flow (see Figure 6) and vertical displacement of the vehicle (see Figure 7). A significant difference between the three tires used can be observed, which help us further in choosing the right type of tire.

Table 1 Input Data

Bumper frequency	30 Hz
Bumper frequency shift	±30%
Bumper height	0,003m; 0,005m; 0,007 m.
Tire mass	37Kg.
Tire damping degree	560 N/(m/s).
Tire elasticity coefficient	243 000N/m Dunlop SP Sport 322 000N/m Bridgestone Turanza RFT 874 000N/m Michelin Radial 11R22.5 XZA
¼ of the vehicle mass	400 Kg
Recovery pistons diameter	30 mm; 45 mm; 60 mm
Tank pressure	30 bar
Hydraulic accumulator volume	7,5L
Hydraulic motor deployed volume	33 cc/rev
Tire radius	0,3 m
Advancement resistibility (for speed of 22 m/s)	868 N

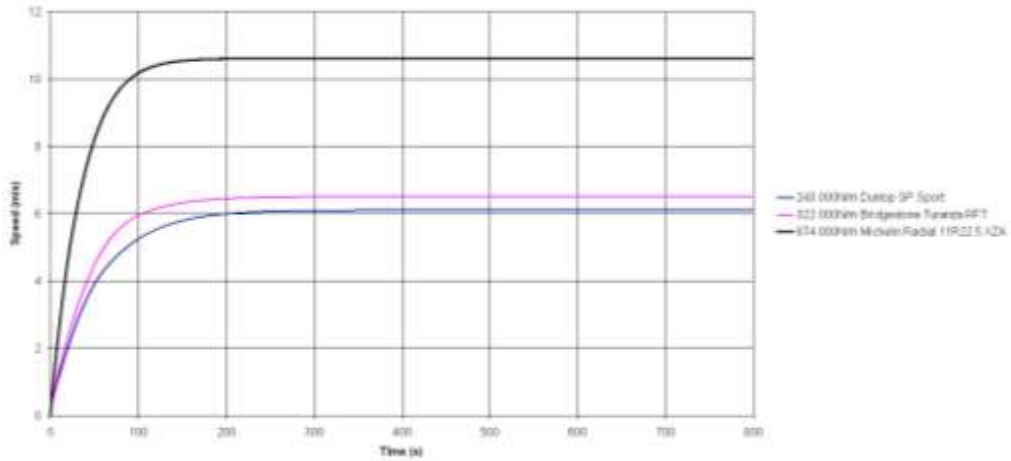


Figure 4: Speed of hybrid hydraulic vehicle

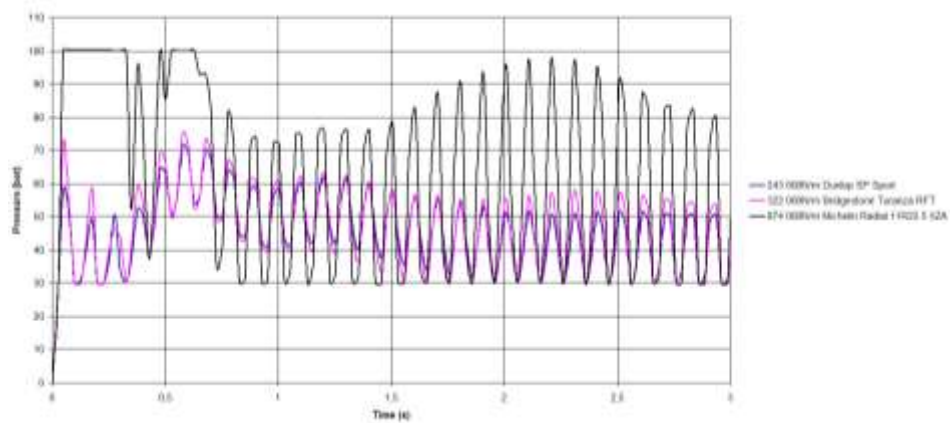


Figure 5: Pressure of hydrostatic motor

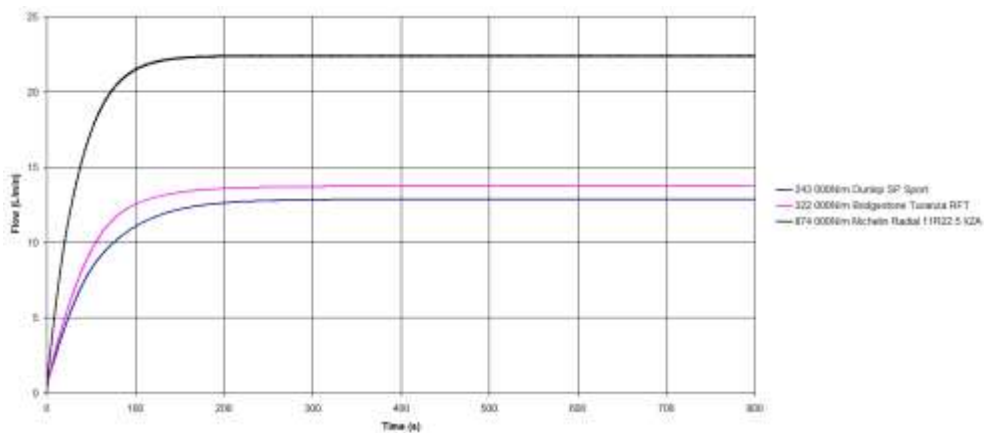


Figure 6: Flow of hydrostatic motor

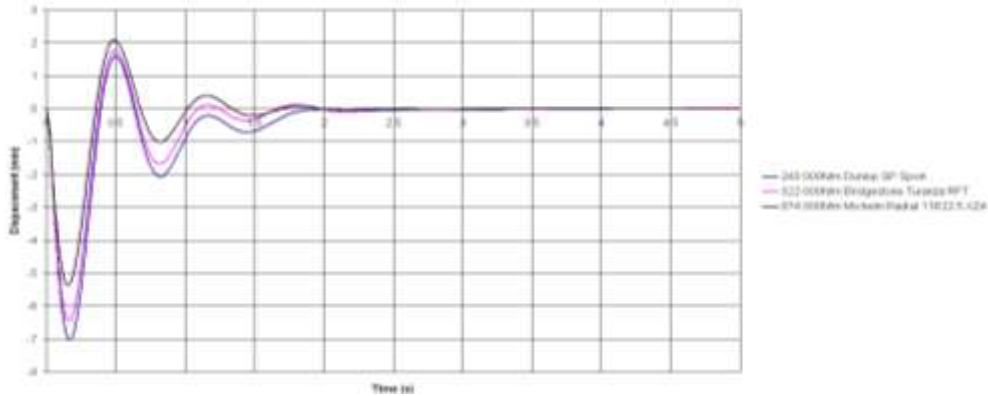


Figure 7: Vertical displacement of the vehicle

The simulation showed that a high vertical stiffness coefficient of the tire represents an advantage in the energy recovery, fact that can be seen in Figure 4.

It can be observed from Figure 5 that for a high vertical stiffness coefficient the pressure reaches 100 bar, while for the other two tires the pressure values are almost the same, around 70 bar.

Similar, the flow of the hydrostatic motor, which values are presented in Figure 6, the stiffness of the tire plays an important role in the energy recovery.

Vertical displacement of the car body is influenced by the vertical stiffness of the tire only when the tire rolls over an uneven surface, it can be observed that a high stiffness coefficient leads to a high comfort rate (see Figure. 7)

Further it is evidenced the recovery speed, of the hydraulic parameters and the damping degree of the damper system by using three types of recovery cylinders with diameters of 30mm, 45 mm and 60 mm.

The simulations were made for a frequency of 30 Hz of the vehicle produced by the oscillations induced by the path, in the first case using Bridgestone Turanza RFT tires, with an elasticity coefficient of 322000N/m and in the second case using Michelin Radial 11R22.5XZA with an elasticity coefficient much higher than 874000N/m [1].

The results are presented in the Figures 8...11.

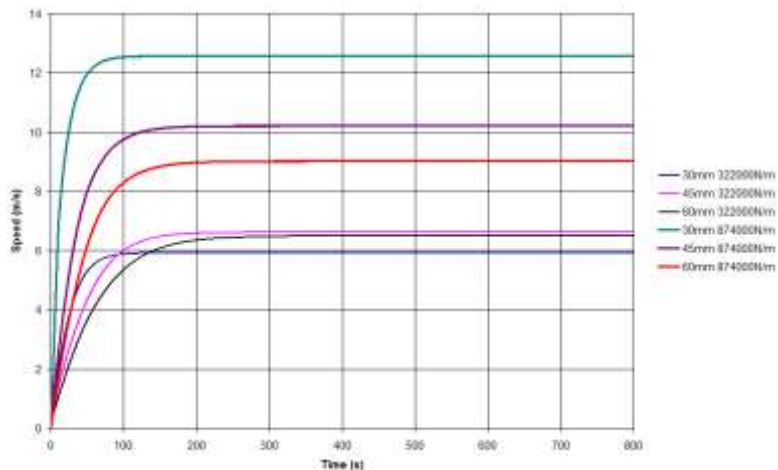


Figure 8: Speed of hybrid hydraulic vehicle

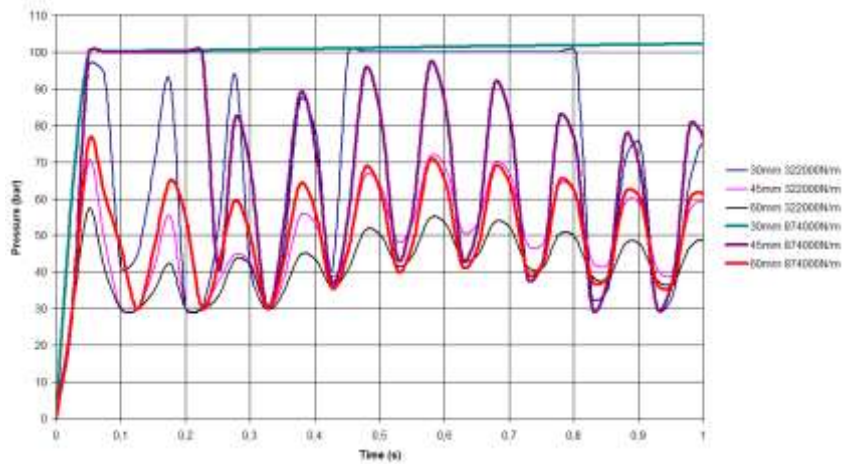


Figure 9: Pressure of hydrostatic motor

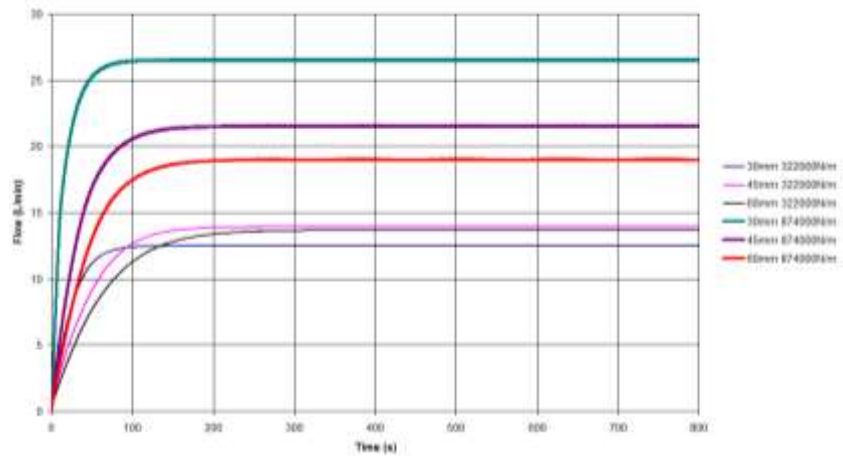


Figure 10: Flow of hydrostatic motor

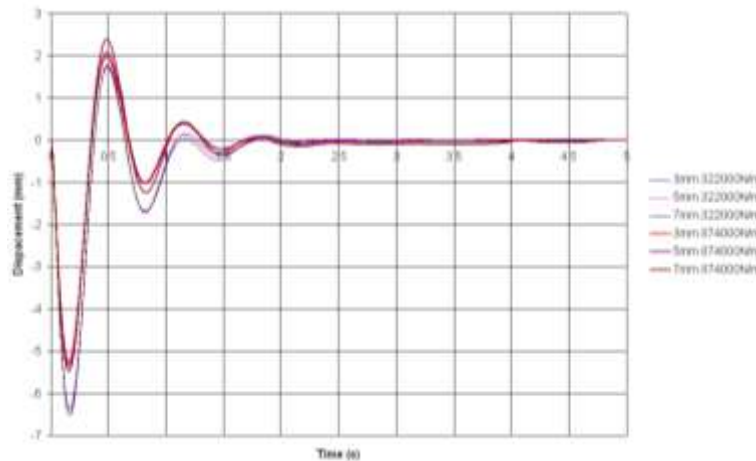


Figure 11: Vertical displacement of vehicle

In Figure 8 it can be observed that a high vertical stiffness coefficient of 874000N/m together with a recovery cylinder of diameter 30 mm, 22% more energy is recovered than in the case a cylinder of 45 mm diameter, and with 30% more energy than in the case of a 60 mm diameter. In the case when the vertical stiffness is of 322000N/m, the ideal recovery cylinder diameter is of 45 mm.

It can be observed from Figure 9 that from all the three chosen dimensions of the recovery cylinder, for a small diameter of the cylinder, 30mm, the pressure reaches the maximum value of 100 bar, at a vertical stiffness coefficient of 874000N/m

The flow value is also ideal in the case of the smallest diameter a high vertical stiffness coefficient, as shown in Figure 10.

In Figure 11 it can be observed that the vertical displacement of the car body doesn't depend much on the tire type or the cylinder diameter, the values been almost the same.

A comparison between the rolling paths of the vehicle was made, first on an uneven road where the system is uniformly excited and secondly on a road where the oscillations frequencies shift with $\pm 30\%$, registered by the left and right side of the recovery system, where the average amplitude is of 5mm. The simulations were made for a vehicle which rolls with Bridgestone Turanza RFT tires with a vertical stiffness coefficient of 322 000N/m. The results of the simulations can be seen in Figures 12...15.

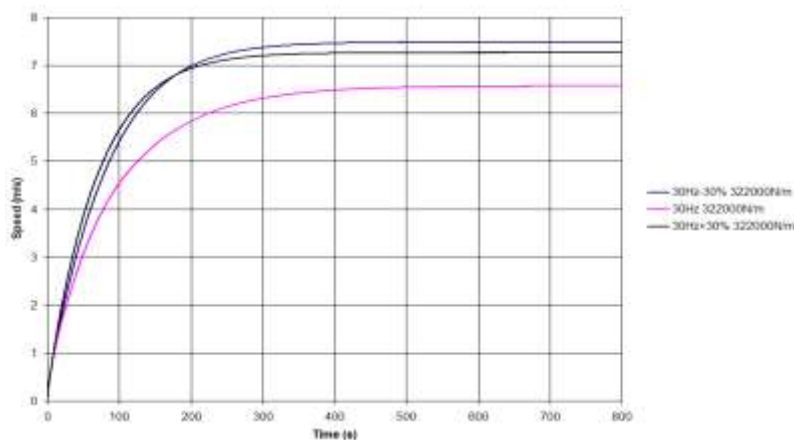


Figure 12: Speed of hybrid hydraulic vehicle

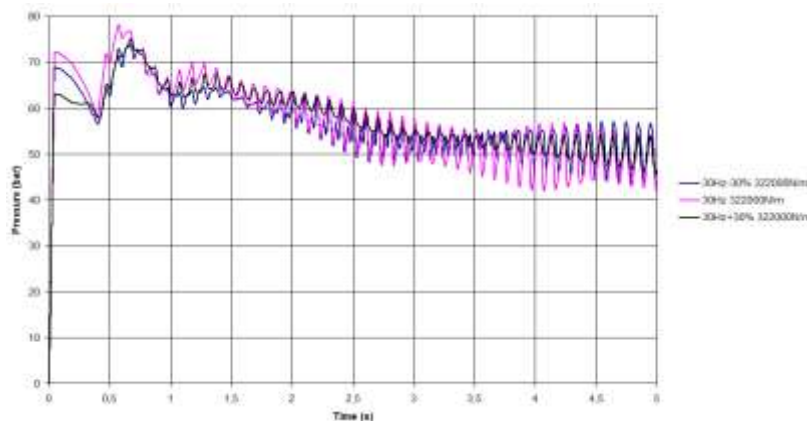


Figure 13: Pressure of hydrostatic motor

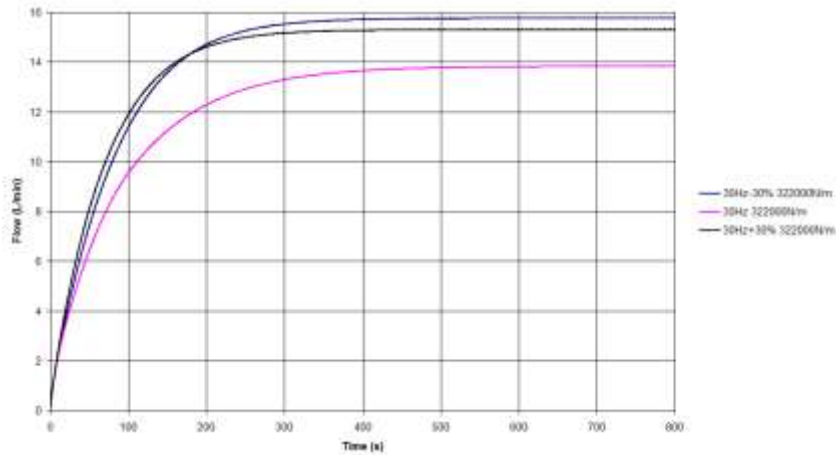


Figure 14: Flow of hydrostatic motor

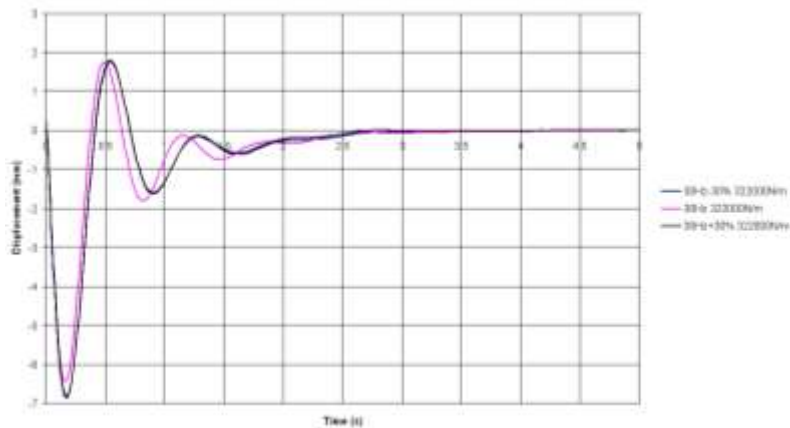


Figure 15: Vertical displacement of vehicle

In Figure 12 it can be observed that at a oscillation shift of -30% the recovered speed is higher with 5 % than in the case when it rolls with a shift of +30% and with 13% than in the case when the recovery cylinders are uniformly excited.

From Figure 13 it can be observed that through different excitation of the recovery cylinders the pressure from the installation has a smaller fluctuation than in the case when it rolls on a uniform excitation of the cylinder.

The excitation difference of $\pm 30\%$ of a damping system generates a rise of the flow rate of the hydraulic liquid compared with the case when the dampers were uniformly excited, with 10% when the frequency is +30% and a rise with 14% when the frequency is -30% smaller on one side of the vehicle, see Figure 14.

Studying the behavior these oscillation shifts have no major effect on the vertical displacement of the vehicle. (Figure 15)

The influence of the height of the unevenness of the road could be accentuated by rolling the vehicle on a path where the oscillations amplitudes is of 3mm, 5 mm and 7 mm.

The simulations were made for a vehicle which is equipped with Bridgestone Turanza RFT tires with a vertical stiffness coefficient of 322000N/m.

The results can be seen in the figures below (see Figures 16...19).

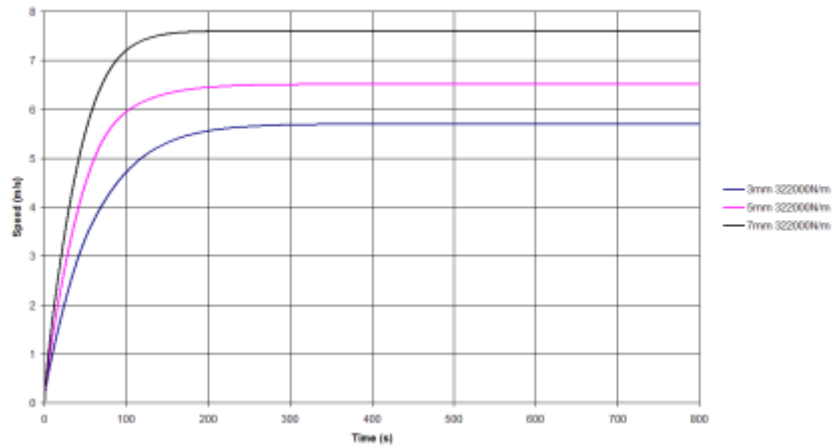


Figure 16: Speed of hybrid hydraulic vehicle

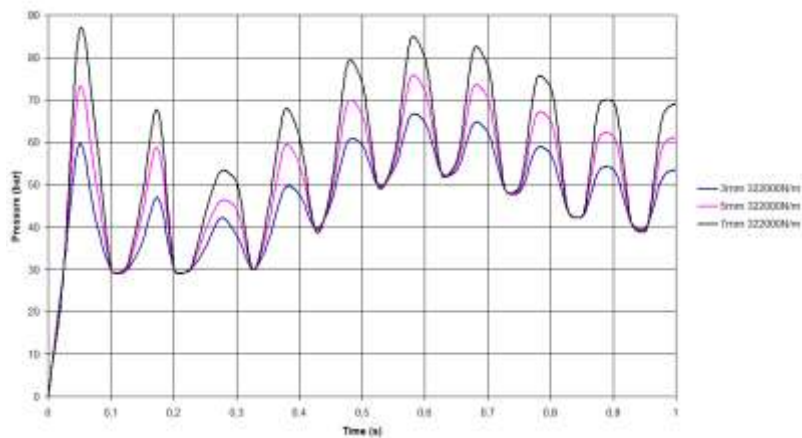


Figure 17: Pressure of hydrostatic motor

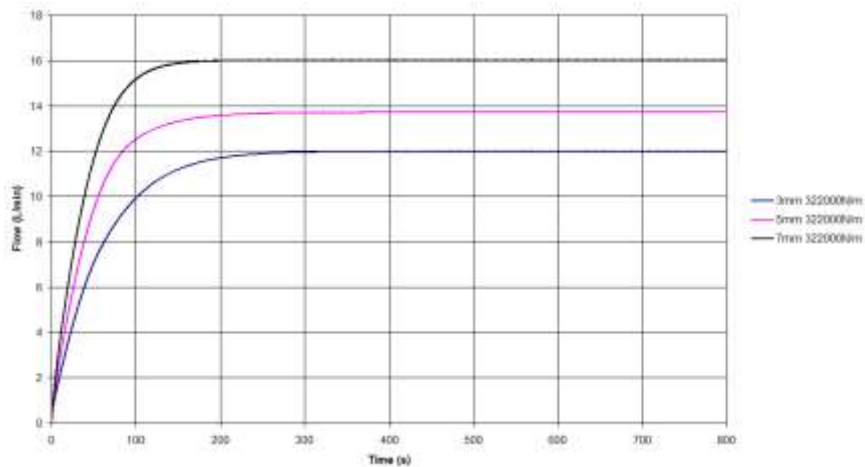


Figure 18: Flow of hydrostatic motor

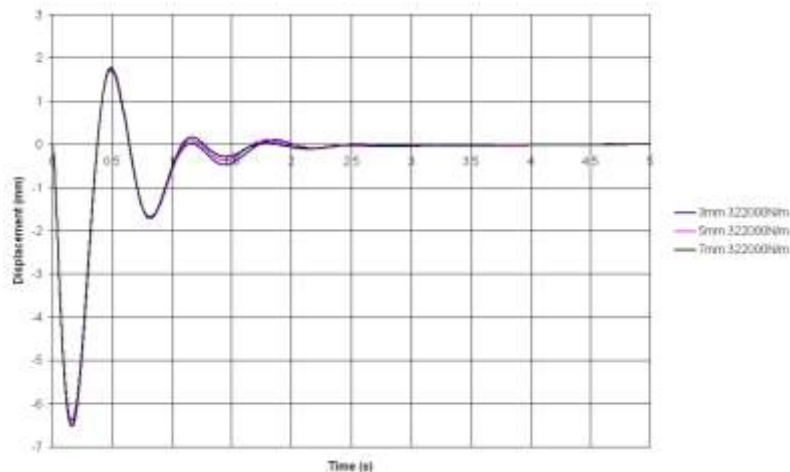


Figure 19: Vertical displacement of vehicle

It can be observed in Figure 16 that when rolling on a path with oscillations of 5 mm we obtain an increase of recovery speed with 13%, compared to a path where the unevenness is of 3 mm, and an increase with 26% compared to 7mm oscillation amplitude.

The pressure in the installation is presented in Figure 17 which shows that by increasing the oscillation amplitude rises the pressure by 20% for a oscillation of 5mm and with 45% for a oscillation of 7mm.

The flow rate of the hydraulic fluid is shown in Figure 18, with the increase of the oscillation amplitude raises the flow rate, fact that denotes the quantity of recovered energy.

From Figure 19 results that regardless of the oscillation amplitudes, 3mm, 5mm or 7mm the car body displacement will remain almost the same, not affecting the comfort.

CONCLUSIONS

As a conclusion to the simulations it can be stated that it is preferred to equip the vehicle with a set of tires with a high vertical stiffness coefficient, which, as Figures 7, 11, 15 and 19 show, has a small influence on the passengers perceived comfort.

It is accentuated the importance of the recovery cylinders dimensions, the simulations shown that by choosing a small diameter of the cylinder and a high vertical stiffness coefficient increases the energy recovered by the system. Also when using a cylinder of 45mm diameter and vertical stiffness coefficient of 322000N/m the results are favorable.

Finally the oscillations frequency needs to be as small as possible, so it can assure a high efficiency of the recovery cylinders, and the height of the oscillations needs to be as high as possible so it recover the maximum of energy but not interacting or affect the passengers comfort.

REFERENCES

- [1] Hans B. Pacejka. "A Tyre and Vehicle Dynamics." Linacre House, Oxford OX2 8D 2006
- [2] AMESim Rev 8B User Support 2008.
- [3] Jörnßen Reimpell . "The Automotive Chassis" Linacre House, Oxford OX2 8D 2001