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THE ANALIZE OF THE INFLUENCE OF THE CONSTRUCTIVE AND FUNCTIONAL FACTORS ON THE PERFORMANCES OF RESONATORS DESIGNED FOR HIDRAULIC HYBRID AUTOVEHICLES

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Abstract: *The resources of hydraulic-hybrid propulsion were not entirely explored; the dynamic phenomenon that appears in the hydraulic fluid are far from being exploited. In consonance with this observation, the fundamental objective of this paper is the use of the dynamic phenomenon, resonance, occurred in the liquid system, with the purpose to optimize the hydraulic propulsion systems designed for auto vehicles.*
In this paper it is intended to explore theoretically and through experiment the possibilities of the use of the resonant phenomenon in hydraulic hybrid propulsion system structures and to achieve to build constructive versions of systems that can be used for the propulsion of auto vehicles.
Keywords: *automotive, hybrid, hydraulic, resonance,*

1. INTRODUCTION

A vehicle to be classified as hybrid, an automobile needs to be equipped with a propulsion system that uses two or more different sources of energy. Generally, the hybridization requires the addition of an energy depositing mechanism and an additional engine, reversible driving mechanism, in order to increase the global performances. The hybrid technology increase the vehicles efficiency by two basic mechanisms: one device that stores energy (which captures energy lostduring brakingorenergy recoveredfrom othercar systems) and more engines that ensure the optimal functioning modes of the vehicles.
The most known hybrid vehicles are the electric hybrid and hydraulic hybrid vehicles. In a hydraulic hybrid propulsion the internal combustion engine, that is used as energy source, usually has lower power, and it can be used at constant operating mode where the specific fuel consumption and the emission values are minimal. A hydraulic - hybrid vehicle stores energy by compressing the gas (nitrogen) within a hydraulic accumulator. The result of this solution is that a high power density was achieved and it can store approximately 70% of the breaking energy, compared to 30% of the breaking energy recovered with batteries of an electric hybrid.Instead,hydraulic accumulatorshavealowerenergy density, which leads toalow energy storagecapacity and constraints regarding energy storage [1].
Afully chargedelectric batterycan rundozens ofkilometers, while a hydraulic accumulatoris dischargedvery quickly.Thesefeatures makehybrid -hydraulicsystemsideal forstop and gooperating conditionscommon, particularlywhen usedinlarger vehiclesthat arealreadyequippedwithhydraulic systemson board.
The main principle is the same for both hybrid systems; there isagenerating sourceof primary energy, which may be aninternal combustion engineora gas turbinecoupled toa pressure generator, a systemfor accumulation ofhydraulic energy, a control system, ahydraulic motor in thewheelswhich transforms thehydraulic energyinto mechanical energy.
The block diagram ofhydraulichybridsystems(Figure 1.) consists of a hydraulic pump,system thatis designed toconvertsome form ofenergy intohydraulic energy; energystorage systems, whicharehydraulic

accumulatorswithgas(nitrogenpressure) engineandhydrostaticsystem thatconvertsliquidwater energyinto mechanical energy.

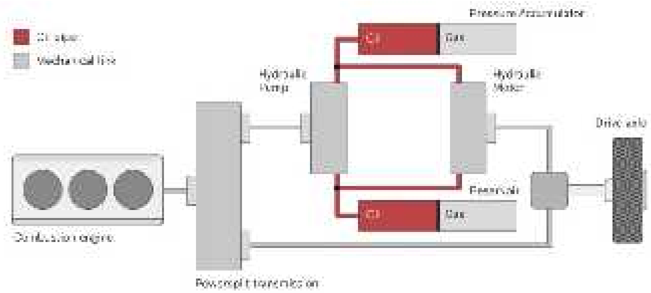

Figure 1.The scheme of a hydraulic hybrid propulsion system [2].

The hydraulichybrid driveisthe recommended solutionapplied invehicle designbecause it ischaracterized by aconsiderable powerdensityobtainedwithconventional buildingstructures; it presentssignificant potential fordevelopmentandoptimizationby applyingthe principles ofalternatingand resonance, which entailsa significant improvement insystem efficiency.
The resonance is the dynamic phenomenon characterized by significant variations in the characteristic parameters of the system (ex.: current in electrical systems, pressure in hydraulic systems, displacement amplitude in mechanical systems) and expressed for certain sets of constructive and functional parameters of the system (mass, elasticity, constant frequencyin mechanical systems).
The variationoflarge, uncontrolledenergygenerated bythe resonance phenomenonmay cause, for example, breaking the crankshaft; butthe phenomenonpresentsapotentialof energywhich must becontrolledand used.
This potentialis intendedto beexploitedin this studyrespectively it isaimed to deduceconstructivesolutionsthat allow resonance tomanifestconstructively.

2. SYSTEM DESCRIPTION

The technical solutionof "hydraulic system for thepropulsionof the vehicle" it isstructurallya driving system, havingin compositionanenergy sourceforhydraulic power generation,transmission pathcontainingthe control systemandactuatorsthat converthydraulic energyinto mechanical energy.
The propulsion system with mechanical resonator integrated in the hydraulic transmission (Figure 2.)the oscillation source 1, driven sinusoidal by a cam or a crank and connecting rod mechanism is drives thepiston2whoserecoveryis ensured bythe elastic element3; itgenerates in thepipe 4 the pressure oscillationsthat propagatestothe execution elements.

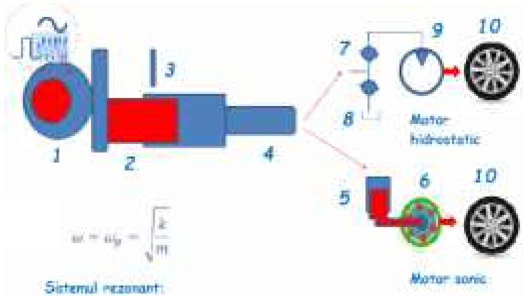

Figura 2. The propulsion system with mechanical resonator

In case of the<u>hydrostatic conversionsolution</u> theoscillationsact aspumpingelementandthroughone-wayvalve7, the liquid in the tank8is moved to thehydrostaticmotor9, whichdrives thewheel10.
In case of the <u>sonic engine solution</u>it is composed ofpiston 5which drives,through acouplingarm andthevalve clutch6, thewheel10.
To identify the functioning and behavior of mechanical-hydraulic resonant propulsion system it was used an ATV type vehicle (All Terrain Vehicle) which in the original version had an unconventional hydraulic

alternating transmission, developed and already studied in the Department of Vehicles and Transport of Transylvania University of Brasov [3].
System diagram is shown in Figure 3. The drive wheel 1 is driven by the valve clutch coupling 2 from the piston rods of hydraulic drive cylinders 3, whose power supply is done at the central double-acting hydraulic cylinder 6 (cylinder unit), driven in turn by crank mechanism - 7. It is powered by the internal combustion engine placed on the front 9. The return of the pistons of the executioncylinders is achieved through four springs 5. The distributor is to create a controllable connection between the two executive branches.

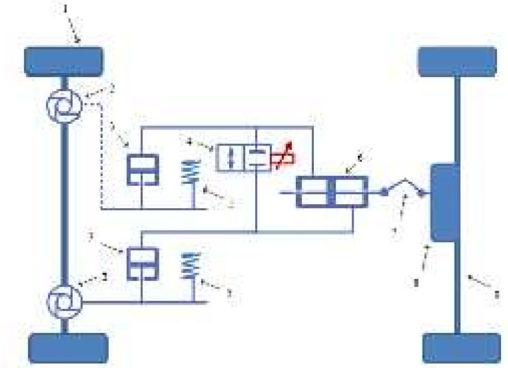

Figura 3.The mechanical-hydraulic resonant propulsion system

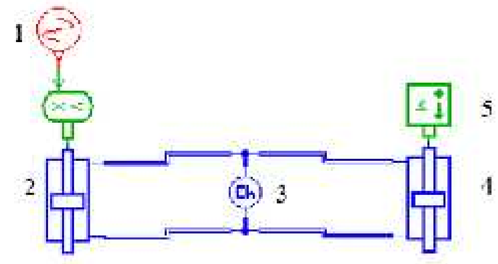

Figura 4. Thehydraulicresonator

The hydraulicresonatorin Fig. Qis formed byoneexcitationsource, double-acting generator piston 2 sonic capacity (hydraulic accumulator) 3, double-acting work piston 4 and inertial mass 5. The disturbanceinducedisa displacement that actson the generator piston sinusoidally.

3. MATHEMATICAL MODEL

The simulations were performe dusing the AMESIM v10 Software. The model is given in figure5:

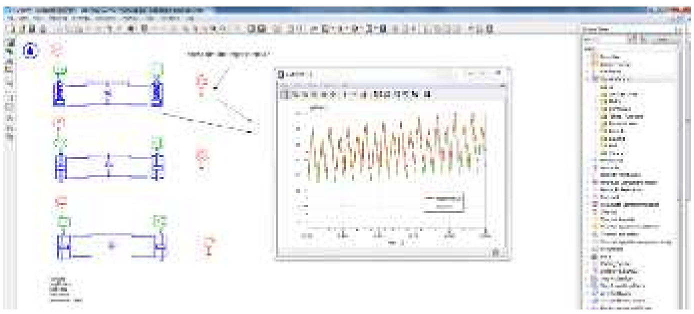

Figure 5 The AMESim models

The mathematical model appliedisbased on thedifferencemethodusingthe Lax – Wendroffconvergencecriteria [4].In this case weneedtwotimelevelstoobtainthesolution at thenewtime-level.The schematic diagram of a Lax-Wendroffevolution scheme is shown in Figure6 andtheapplication of this scheme totheadvectionequation (Eq.1) isstraightforward [5].

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial x} = 0, \qquad \text{[Eq. 1.]}$$

More specifically, the “half-step” valuescanbecalculated as,

$$u_{j\pm\frac{1}{2}}^{n+\frac{1}{2}} = \frac{1}{2}\left(u_j^n + u_{j\pm1}^n\right) \pm \frac{\alpha}{2}\left(u_{j\pm1}^n - u_j^n\right) + O(\Delta x^2), \qquad \text{[Eq. 2.]}$$

sothatthesolution at thenewtime-levelwillbe,

$$u_j^{n+1} = u_j^n - \alpha\left(u_{j+\frac{1}{2}}^{n+\frac{1}{2}} - u_{j-\frac{1}{2}}^{n+\frac{1}{2}}\right) + O(\Delta x^2), \qquad \text{[Eq. 3.]}$$

$$= u_j^n - \frac{\alpha}{2}\left(u_{j+1}^n - u_{j-1}^n\right) + \frac{\alpha^2}{2}\left(u_{j+1}^n - 2u_j^n + u_{j-1}^n\right) + O(\Delta x^2), \qquad \text{[Eq. 4.]}$$

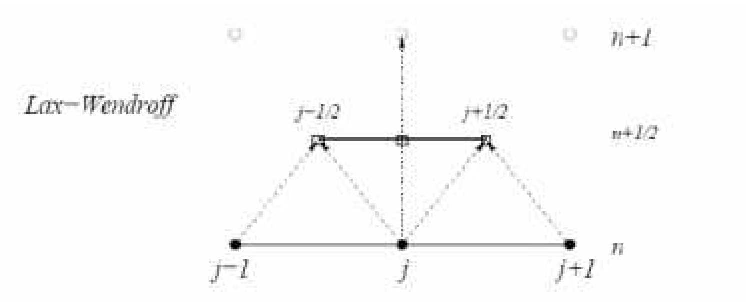

Figure 6. Schematic diagram of a Lax-Wendroffevolution.

4. VALIDATION OF THESIMULATION MODELS

To study the influence of several constructive and functional factors through simulation it is necessary the calibration of the mathematic model parameters (for ex.: flow coefficient, damping coefficient, flow loss coefficient, etc.) for the chosen solution, in order to have the smallest error between the simulation and experimental results.

After correlating the mathematical models with the experiments the following influences on the work piston were studied by simulation with AMESimsoftware: the influence of the acting frequency of the generator piston, influence of the displacement amplitude of the generator piston, the influence of the initial pressure within the hydraulic system and the influence of the generator piston diameter.

The correlation was found acceptable between the experimentally determined values and those obtained by simulation, trends and obtained phases. The mean error found is below 10%, acceptable for dynamic processes. The general appearance of the curve it is simulated values well below the experimental aspect debit due coefficients (Figure 7.)

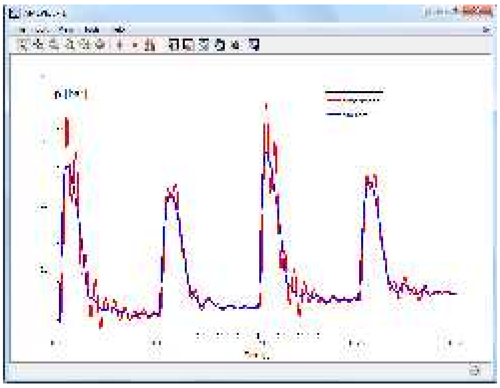

Figure 7. Comparison between experimental and simulation results.

5. SIMULATION RESULTS

In the paper it was intended to identify the evolution of the working pressure in differentresonator configurations and how it is influenced by structural and functional factors.

Working pressure is considered the main research parameter aiming to maximize it, given that it contributes to the car's traction performance.

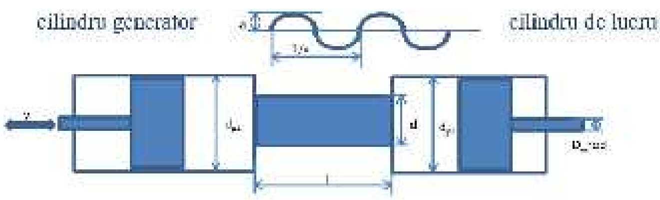

Figure 8. Geometric parameters

5.1 Influence of the displacement amplitude of the generator piston on the system pressure

For the sinusoidal perturbance, the considered simulation parameters are: initial pressure p=0 bar, the generator piston working frequency v=20 Hz, the piston displacement amplitude of the a=5, 10, 15 mm, pipe length l=500mm, pipe diameter d=3mm, generator piston diameter d_{pl}=20mm, Work piston diameter d_{p2}=20mm.
The analyze of the pressure evolution developed in the work piston shows how the resonance is developing in different conditions (fig9)
There is apressureascending evolution, no matterthe amplitude, but the way of growthis significantly different, higheramplitudesareensuringstrongergrowth.
Regardless of thetechnical solutionthe pressureamplitudeis related tothe pressure waves amplitude, the development processes of resonance are stable.

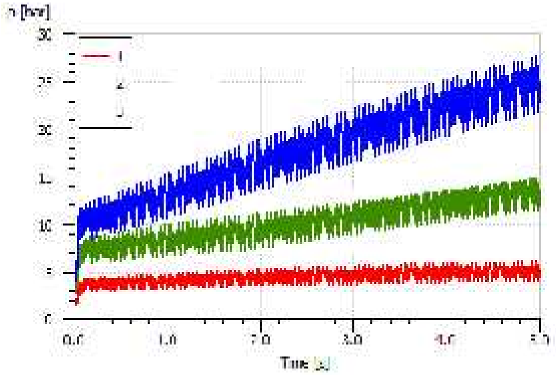

Figure1.Influence of the displacement amplitude of the generator piston on the working pressure; 1 – a = 5 mm, 2 – a=10 mm, 3 – a=15 mm

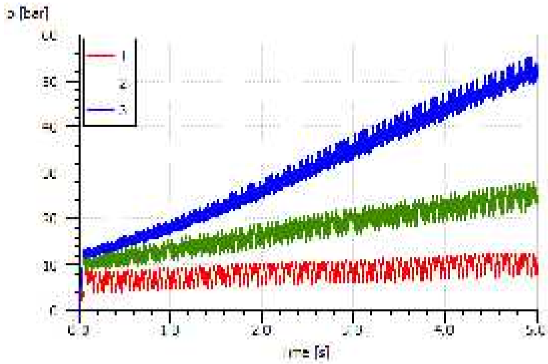

Figure 10.Influence of the displacement frequency of the generator piston on the working pressure; 1 – f =10 Hz, 2 – f=20 Hz, 3 –f=30 Hz

5.2 Influence of the displacement frequency of the generator piston on the working pressure

The considered simulation parameters are: initial pressure p=0 bar, the generator piston working frequency v=10, 20, 30 Hz, the piston displacement amplitude of the a=15 mm, pipe length l=500mm, pipe diameter d=3mm, generator piston diameter d_{pl}= 20mm, Work piston diameter d_{p2}=20mm.
Theanalyze of the graphic in fig 10 shows that the growth of the frequency leads to a faster amplification of the pressure waves.
It appears thatat high frequencies, althoughoscillations are highly distorted, the oscillation amplitude is maintained higher. Extrapolation of the results demonstrated by simulation, shows a monotonically increasingdevelopment of the residualpressureinduced by resonance.

5.3 Influence of the initial pressure within the system on the hydraulic system pressure evolution

The considered simulation parameters are: initial pressure p=0, 5, 10 bar, the generator piston working frequency v=20 Hz, the piston displacement amplitude of the a=15 mm, pipe length l=500mm, pipe diameter d=3mm, generator piston diameter d_{pl}= 20mm, Work piston diameter d_{p2}=20mm. the initial pressure within the system is a stabilizing factor for the double acting effect.
In case of thesystembased onpiston withdouble effect, the pressureincreasesabout the same,no matterinitial pressure(Figure 11). There is aslight differencemarked bya significant increase, faster increase of thepressurewhen thepressure isreduced, which could be explainedwithreserves, ahigher elasticityofthe liquid columnto a pressurewhich isreduced.

5.4 Influence of the generator piston diameter on the system.

The considered simulation parameters are: initial pressure p=0 bar, the generator piston working frequency v=20Hz, the piston displacement amplitude of the a=15 mm, pipe length l=500mm, pipe diameter d=3mm, generator piston diameter d_{pl}= 20, 30, 40mm, Work piston diameter d_{p2}=20mm.

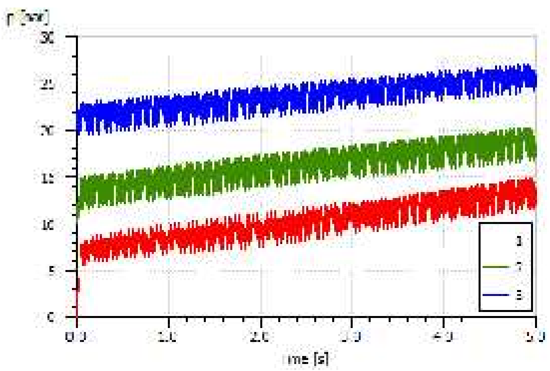

Figure. 11. Influence of the initial pressureon the working pressure; 1 –p = 0 bar, 2 – p=10 bar, 3 – p=20 bar

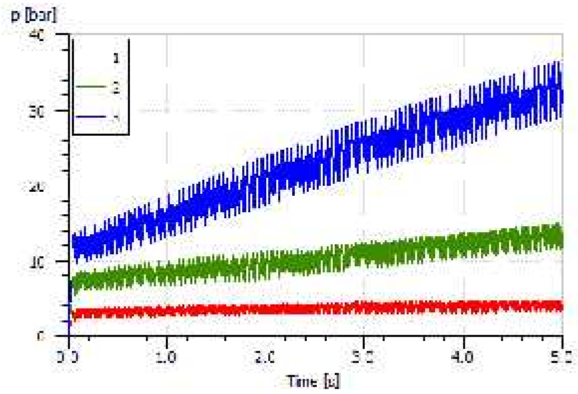

Figure 12. Influence of the generator piston diameter on the system working pressure; 1 – dp1 = 20 mm, 2 – dp1=30 mm, 3 –dp1=40 mm

The evolution of the pressure in the hydraulic system for different piston diameters of the generator (Figure 12) shows the trend identified in previous studies: unstable operation at low values of the volume displaced by the piston of the generator, the amplificationof moderatedouble-effectsystemandincreasedpulseamplification. It notes that the influence of the generator, the amplitude of the pressure waves it is approximately proportional increase in the volume displaced.

CONCLUSIONS

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1. The resonance in mechanical-hydraulic systems is a stable and controllable phenomenon with a significant energy potential due to the specific wave propagation in liquids.
2. The propagation ofoscillationsin theliquiddetermines themaximum speed ofthe order of 2m/ s, values significantlylower than the averagespeedof6 m/ stypical conventional hydraulic systems, values involving reduced hydraulic losses and increase the efficiency of hydraulic transmission.
3. The dynamic phenomena that manifests in liquid shave a high complexity and for a relevant description it is necessary to combine several theoretical and experimental research methods.
4. The specificresonance of themechanical systemsis more evidentandpronouncedinoscillation amplitudegeneratedcompared to those inhydraulic systemswhich are very sensitive tocharacteristic parametersvariation.

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REFERENCES

[1]. Kevin Michael Zaseck Modeling and Control of Hydraulic Linear and Free-Piston Engines, Adissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Mechanical Engineering) in The University of Michigan.
[2]. http://www.car-engineer.com/bosch-hydraulic-hybrid-powertrain-developped-with-psa/
[3]. Petric, A-A.: Îmbunătățirea performantelor energetic și ecologice ale autovehiculelor prin utilizarea propulsiei hybrid hidraulice, teză de doctorat.
[4]. ***, LMS Imagine. LabAMESim Reference Manual, Rev.10 - LMS International, June 2013.
[5]. R. Luciano, Numerical Methods for the Solution of Partial Differential Equations, Lecture Notes for the COMPSTAR School on ComputationalAstrophysics, 8-13/02/10, Caen, France.