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THE ANALYSIS OF SOME HYDRAULIC POSSIBILITIES FOR RECOVERY-STORAGE OF THE VARIABLE MOVEMENT ENERGY OF THE VEHICLES, USING AN ADDITIONAL MOBILE SOLID MASS

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Abstract: *In the paper it is analyzed the hydraulic possibilities of recovery and storage for the variable movement energy (rectilinear and horizontal) of vehicles, using an addition mobile solid mass and hydraulic scheme containing a central tank, branching pipes and hydraulic pumps, actuated directly of the mobile object and hydraulic accumulators. There are making evident the determinant influence factors and the practical possibilities of energy recovery degree increasing. In the study is showed a numerical application.*

Key words: *recovery, energy, pumps.*

1. Introduction

In the horizontal and variable linear or curvilinear movement of vehicles appear inertial forces:

$$F = m \cdot a = \frac{G}{g} \cdot a \ \text{[N]} \quad (1)$$

or

$$F = m \cdot a_{centrif} = \frac{G}{g} \cdot R \cdot \omega^2 = \frac{G}{g} \cdot \frac{v^2}{R} \quad (2)$$

Where G is the vehicle weight, m the equivalent mass, a the rectilinear acceleration, $a_{centrif}$ the centrifugal acceleration, v the vehicle speed, R the radius of horizontal road curve and ω the angular speed.

If the road length is l and the movement time is t, there are obvious the relations:

$$a = \frac{l}{t^2}, \ t = \sqrt{\frac{l}{a}}.$$

There is defining the vehicle energy in the variable movement time.

$$E_{\text{var}\,iable.movement} = F \cdot l = \frac{G}{g} \cdot a \cdot l = \frac{G}{g} a^2 \cdot t^2 \quad (3)$$

This potential energy, unused, loosed when the uniform movement is back, can have sizeable values. The inner recovery of this energy is not that simple as it likes. The F force must have a mobile mass support. That force can not be used static; it must perform a useful mechanic work.

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That can be made with a solid or liquid mass inside of vehicle, where appear the inertial force. That mass perform a relative movement in ratio with the vehicle, actuating a mechanism, an engine, whom energy (mechanic, hydro-pneumatic, electric), can be accumulated/stored and used for different purposes and in different places.

In the work [1, 2] is presented possible recovery assemblies with hydraulic energy storage in gas-loaded accumulators. Because little values of the recovered energy, authors continued the research with new variants and technical solutions.

In the presented paper, there is considered an additional solid mass, which can perform a horizontal rectilinear movement, during the vehicle variable movement, on a horizontal board with metal balls, the come-back to the neutral position (of uniform movement or repose) being attained with some devices with spring.

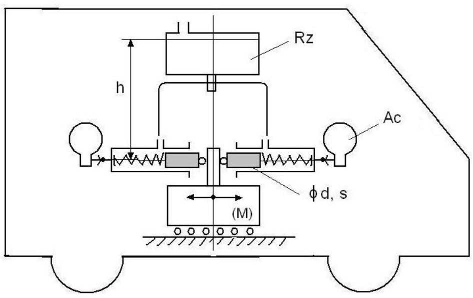

Fig. 1. *Vehicle with energy recovery system*

2. Theoretical considerations

It is follow a hydraulic accumulation of energy, a small volume V_{acc}, with a highest pressure p_{acc}, where the purpose is the usage of some pumps with plunger piston, actuated directly of the mobile mass (figure 1) or through a teethed cam (figure 2). In figure 3 the pump cylinder is mobile, solidary with the mass *M*. In figure 4 is showed how is actuated a rotary hydraulic pump through a piston and a rack solidary with *M*. It is using a central tank with liquid (water, oil) R_z, connecting pipes with one way valve and hydraulic accumulators A_c.

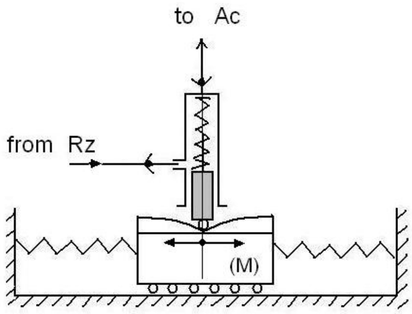

Fig. 2. *Pump with plunger piston, actuated directly of the mobile mass*

The piston pump flow-rate with diameter *d* and displacement *s* (spring come-back) is:

$$Q_p = \eta_{v,p} \cdot v_p \cdot \frac{\pi \cdot d^2}{4} \text{ [m}^3\text{/s]} \qquad (4)$$

the piston speed v_p being the mobile mass speed (variable).

In the compute of the liquid volume send to the accumulator is not necessary the value of v_p because:

$$V_{acc} = \eta_{v,p} \cdot \frac{\pi \cdot d^2}{4} \cdot s \text{ [m}^3\text{]} \qquad (5)$$

The accumulated liquid pressure is:

$$p_{acc} = \eta_{m,p} \cdot \eta_{tr} \cdot \frac{4}{\pi} \cdot \frac{F}{d^2} \text{ [Pa]} \qquad (6)$$

The energy stored during a variable movement is:

$$E_{acc} = p_{acc} \cdot V_{acc} = \eta_p \cdot \eta_{tr} \cdot F \cdot s \quad (7)$$

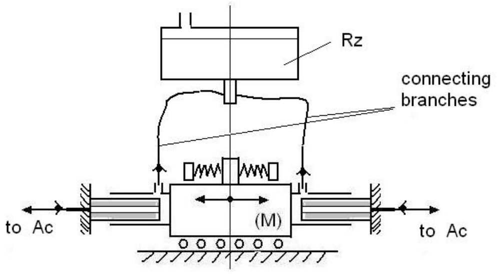

Fig. 3. *System with mobile pump cylinder*

Where η_p is the total efficiency of the pump, and the partial efficiencies are $\eta_{m,p}$ (mechanic) $\eta_{v,p}$ (volume). The transport efficiency η_{tr} is about of ejected fluid movement from pump to the accumulator. The fluid intake from tank R_z is not a problem because is placed on a *h* quota which overcharge the pump.

In the case of the rotary hydraulic pump usage must be solve some technical problems like returning to the neutral position.

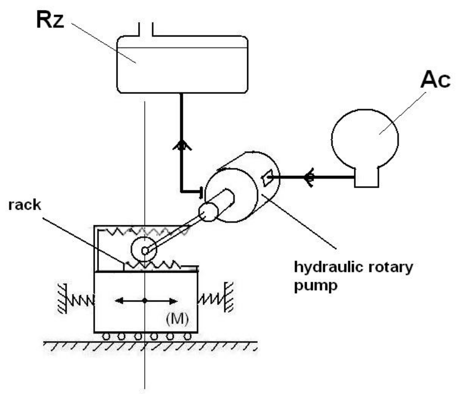

Fig. 4. *System with rotary hydraulic pump*

The volume rotary pump flow rate is:

$$Q_{HRP} = \eta_{v,hpr} \cdot q \cdot n \cdot \frac{10^{-6}}{60} \cdot 10^3 \text{ [l/s]} \quad (8)$$

with cubic capacity q [cm^3/rot], speed n [rot/min] and the volumetric efficiency $\eta_{v,p}$.

The speed of translation of the rack v_r is equal with the mobile mass speed.

The volume of the accumulated liquid:

$$V_{acc} = t \cdot Q_{HRP} \text{ [m}^3\text{]} \quad (9)$$

The mechanic power in the rack:

$$N_r = F \cdot v_r \text{ [W]} \quad (10)$$

The hydraulic power of the pump:

$$N_{HPR} = \eta_{HPR} \cdot \eta_{gear} \cdot N_r \text{ [W]} \quad (11)$$

The pressure in the accumulator is:

$$p_{acc} = \eta_{tr} \cdot \frac{N_{HRP}}{Q_{HRP}} = 6 \cdot 10^4 \cdot \eta_{tr} \cdot \eta_{gear} \cdot \eta_{m,hrp} \cdot \frac{F \cdot v_r}{q \cdot n} \quad (12)$$

Referring to calculus of the recovered and stored energy, the factor *t* represents the duration of a variable movement one event from start ups, accelerations, decelerations, stops of the vehicle. There are noted with *Z* the vehicle number of daily movement hours, from that the part *X* represents the variable movement. If duration of one “event” is *t* seconds, with a value of the acceleration *a* (can be considered a statistic average value for different situations), the daily number of “events” is:

$$Y = \frac{Z \cdot X \cdot 3600}{t}$$

[variable movements / working day] (13)

This is an example: Z = 8 hours/day, X = 6,25 %, t = 15 sec., results: Y = 120 "events" in a day.

The recovery degree of the energy relative variable movement of mass $m = G/g$ inside of vehicle is:

$$R_{ec} = \frac{E_{acc}(hydraulic)}{E_{variable.movement}} = \eta_p \cdot \eta_{tr} \cdot \frac{s}{l} = \\ = \eta_p \cdot \eta_{tr} \cdot \frac{s}{a \cdot t^2} \quad (14)$$

The recovered and stored of energy can be used in certain scopes. Their conversion in mechanical energy for certain hydro-mechanical drives: servo/controllers (servo-assisted steering, servo-assisted brake, hydraulic jack, hydro-pneumatic starter, certain actuations with little consumption of energy) or in other locations (repairing shops, garages, pump stations).

3. Numerical application

It is considered the technical solution with plunger-piston pump, with ϕd = 25 mm; s = 0,5 m; m = 1500 kg; a = 2 m/s^2; $\eta_{m,p}$ = 0,96; $\eta_{v,p}$ = 0,99; η_p = 0,95; η_{tr}= 0,92.

There are calculated: V_{acc} = 0.24 l; p_{acc} = 5,5 bar; E_{acc} = 133 N·m.

For 120 events on a day: V_{acc} = 29 l; E_{acc} = 16 kN·m = 4.45 W·h.

4. Conclusions

This study, and finely the equation (14), shows the recovery degree limitations and their technical difficulties. There are not negligible either the investment or exploitation expenses. The performances of the modern hydraulic machines or transmissions, leads to high values for efficiencies: η_p, η_{tr}, η_{gear}. Practical, the problem is the sensible increase, significant, of the recovery degree R_{ec}. For the examples considered by the authors, *s/l* = 1/100. The decreasing of l = $a \cdot t^2$ and increasing of s, leads to good effects.

To compute the energy recovered / accumulated / used from the solid mass M, in equation (14) are equalized s with a·t^2, the energetic indicator becoming exploitation degree, efficiency:

$$R'_{ec} = \eta_p \cdot \eta_{tr} \quad (15)$$

or

$$R''_{ec} = \eta_p \cdot \eta_{tr} \cdot \eta_{gear} \quad (16)$$

for the rotary pump solution. For the example showed in this paper, results R'_{ec} = 87,5% and R''_{ec} =81%.

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