A STUDY ON AN ENERGY HARVESTING SYSTEM FROM SPEED BUMP

NGHIÊN CỨU VỀ HỆ THỐNG THU NĂNG LƯỢNG TỪ GỜ GIẢM TỐC XE CƠ GIỚI

Luyen Van Hieu*1 , Nguyen Ba Chinh[2]
[1]Faculty of Automobile Engineering - Hung Yen University of Technology and Education
[2]The Central College of Transport No2 II

ABSTRACT

The article presents research findings on an energy harvesting system using speed bump devices for motor vehicles while on the road. These speed bumps are installed at various traffic points, specifically where vehicular traffic needs to slow down for safety. The paper successfully introduces a system model that has been simulated using the Matlab-Simulink program. The results also demonstrate the potential energy source that can be harnessed from this energy.

Keywords: *Speed bump; Energy from Speed bump.*

TÓM TẮT

Bài báo trình bày kết quả nghiên cứu về hệ thống thu năng lượng từ bằng gờ giảm tốc cưỡng bức xe cơ giới khi di chuyển trên đường. Những gờ giảm tốc này được lắp đặt tại các điểm giao thông, nơi các phương tiện cơ giới cần phải giảm tốc độ để đảm bảo an toàn giao thông. Bài báo giới thiệu thành công một mô hình hệ thống đã được mô phỏng bằng chương trình Matlab-Simulink. Kết quả cũng chứng minh nguồn năng lượng tiềm năng có thể được tận dụng từ nguồn năng lượng này.

Từ khóa: *Gờ giảm tốc; Năng lượng từ gờ giảm tốc.*

1. MAKE A PROBLEM

Transportation plays an indispensable role in our daily lives, especially the use of vehicles. Ensuring safety in traffic involves crucial speed regulation, with numerous measures available, among which speed bumps are widely employed today. However, the commonly used speed bumps lack the capacity to harness energy. Failing to exploit this energy source represents a wastage. Therefore, researching speed bumps capable of harvesting energy from vehicular motion is a significantly meaningful endeavor. There have been studies on the topic of speed bump energy harvesting for vehicles, as evidenced by works such as [1, 2, 3, 4, 5, 6, 7, 8]. However, these studies predominantly employ mechanical power transmission. Due to the advantages of easy installation and operation, and there have been studies utilizing hydraulic drive systems for energy harvesting [9, 10]. Therefore, hydraulic drive systems should be considered for research and application in harvesting energy from speed bumps.

2. THE SYSTEM DESCRIPTION

The energy harvesting system, utilizing speed humps to reduce the speed of a vehicle, can be illustrated by the following diagram:

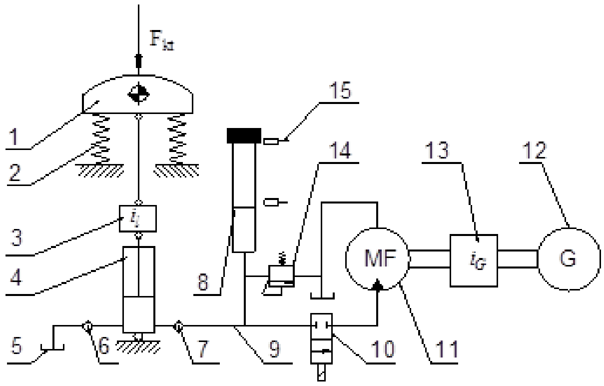

Figure 1: Diagram of the energy harvesting system using speed bump (EHSSB):
1 - Speed hump; 2 – Spring return;
3 – Transmission rod with ratio i_l; 4 – Hydraulic cylinder assembly; 5 – Hydraulic oil reservoir;
6, 7 – One-way hydraulic valves; 8 – Hydraulic accumulator tank for gravity load; 9 – High-pressure hydraulic oil path; 10 – Hydraulic valve; 11– Hydraulic motor; 12 - Generator;
13 – Mechanical transmission system with gear ratio i;
14 – Safety valve; 15 – Stroke switch;
F – Force exerted by the weight of the vehicle.

Based on the impact of the vehicle's weight, the speed reducer is displaced downward, compressing spring 2. After the speed reducer is no longer affected by the vehicle's weight, spring 2 releases, returning the speed reducer to its initial position. As the speed reducer moves downward, through the drive system of connecting rod 3, the piston of the hydraulic cylinder assembly 4 moves, compressing hydraulic oil. The oil is then pushed through one-way valve 7, through the high-pressure hydraulic oil path 9, and is loaded into the accumulator tank 8, where energy is stored. This stored energy is retained until reaching the position of operational valve number 15. At this point, it activates hydraulic valve 10 to open. Hydraulic oil is then pushed to the hydraulic motor 11 for operation through the mechanical transmission system 13, thereby driving the generator 12 into operation.

3. THE SYSTEM MODELING

Based on the working principle of the EHSSB shown in Figure 1, a mathematical model is proposed to demonstrate the system dynamics.

3.1. Modeling of speed bump

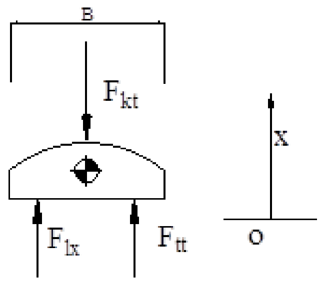

Figure 2. Schematic of the translational motion with speed bump

From the diagram in Figure 1, we have the following schematic:

Applying Newton's Second Law, we have: $m.\ddot{x} = (F_{lx} + F_{tt}) - F_{kt}$ (1)

$F_{lx} = K.x$ (2)

Where: m - Mass of the speed bump (kg); F_{kt} - Force exerted by the vehicle load on the speed bump (N); F_{lx} - Reaction force due to the spring elasticity (N); K – Spring constant; x - Displacement of the speed bump in the vertical direction (m); F_{tt} - Reaction force from mechanical transmission rod (N).

3.2. Model of the hydraulic cylinder and transmission rod

Using hydraulic cylinder such as a pump and ignoring the mass, the model of the hydraulic cylinder is described by the following equations [11]:

$$F = p_c A + F_C \quad (3)$$

$$q = A.v(t) \quad (4)$$

$$\frac{dx}{dt} = v(t) \quad (5)$$

$$v = v_R - v_C \quad (6)$$

$$A = \frac{\pi . D_{pt}^2}{4} \quad (7)$$

$$F_C = \begin{cases} (x - x_E).K_p.v(t), \text{if } x > x_E, v > 0 \\ (x - x_R).K_p.v(t), \text{if } x < x_R, v < 0 \\ 0 \quad \text{otherwise} \end{cases} \quad (8)$$

$$x_E = S - x_0 \quad (9)$$

$$x_R = -x_0 \quad (10)$$

Where: F is the force developed by the cylinder; v(t) is the cylinder rod velocity; v_R, and v_C are the absolute velocities of the cylinder rod and cylinder case, respectively; A is the surface area of the piston; p_c is the pressure in the compression chamber; q is the flow rate through port A out of the cylinder; x is the piston position; x_0 is the initial distance between the piston and cap A; F_C is the hard stop force; x_E is the distance traveled by the piston to fully extend from the initial position; x_R is the distance the piston can travel to fully retract from the initial position; K_p is the penetration coefficient; S is the piston stroke; and D_{pt} is the diameter of the piston.

The relationship between Reaction force from mechanical transmission rod (F_{tt}) and the hydraulic cylinder force (F) is given by the transmission ratio (i_l).

$$F_{tt} = F.\, i_l \quad (11)$$

i_l - The transmission ratio from speed bump to the rod of the hydraulic cylinder.

3.3. Model of the pipeline is written in the form of pressure loss

Assuming that the fluid is in a laminar flow state, the pressure drop can be expressed as [11].

$$\Delta p = f \frac{(L + L_{eq})}{D_H} \frac{\rho}{2A_L^2} q.|q| \quad (12)$$

$$f = \begin{cases} K_s / R_e \text{..........................} for....R_e <= R_{eL} \\ f_L + \dfrac{f_T - f_L}{R_{eT} - R_{eL}}(R_e - R_{eL}) \text{..........} for....R_{eL} < R_e < R_{e_T} \\ \dfrac{1}{(-1.8\log_{10}(\dfrac{6.9}{R_e} + (\dfrac{r/D_H}{3.7})^{1.11}))^2} \text{.......} for....R_e >= R_{eT} \end{cases} \quad (13)$$

$$R_e = \frac{q.D_H}{A_L.\nu} \quad (14)$$

Where: Δp - Pressure loss along the pipe due to friction; q - Flow rate through the pipe; R_e - Reynolds number; R_{eL} - Maximum Reynolds number at laminar flow; R_{eT} - Minimum Reynolds number at turbulent flow; K_s - Shape factor that characterizes the pipe cross section; f_L - Friction factor at laminar border; f_T - Friction factor at turbulent border; A_L - Pipe cross-sectional area; D_H - Pipe hydraulic diameter; L - Pipe geometrical length; L_{eq} -Aggregate equivalent length of local resistances; r - Height of the roughness on the pipe internal surface; ν - Fluid kinematic viscosity.

3.4. Modeling of check valve

The valves in the piston valve or base valve can lead to a decrease in the flow pressure. The check valves above are regarded as thin wall holes, and thus the pressure drop can be expressed as [11]:

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$$q_{vi} = C_d A_{vi}\sqrt{\frac{2\Delta P_{vi}}{\rho}} \quad (15)$$

$$\text{and } \Delta P_{vi} = \frac{q_{vi}^2 \rho}{2C_d^2 A_{vi}^2} \quad (16)$$

$$A_{vi}(p) = \begin{cases} A_{leak}, \text{for} \ldots p <= p_{crack} \\ A_{leak} + k.(p - p_{crack}) \quad \text{for} \ldots p_{crack} < p < p_{max} \\ A_{max}, \text{for} \ldots p >= p_{max} \end{cases} \quad (17)$$

$$k = \frac{A_{max} - A_{leak}}{p_{max} - p_{crack}} \quad (18)$$

Where: Δp_{vi} - The pressure drop of the check valve i; q_{vi} - The flow rate of the check valve i; C_d - The flow coefficient; ρ - The kinetic density of oil; A_{vi} - The cross area of the check valve i; A_{max} - Fully open valve passage area; A_{leak} - Closed valve leakage area; p_{crack} - Valve cracking pressure; p_{max} - Pressure needed to fully open the valve.

3.5. Model of the weight-loaded accumulator

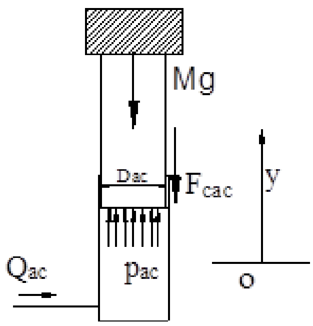

Figure 3. The diagram of the weight-loaded accumulator

Applying Newton's Second Law, we have:

$$M.\ddot{y} = \frac{\pi D_{ac}^2}{4} p_{ac} - (Mg + F_{cac}) \quad (19)$$

$$F_{cac} = \begin{cases} (y - y_E).K_{pac}.v(t), \text{if } y > y, v > 0 \\ (y - y_R).K_{pac}.v(t), \text{if } y < y_R, v < 0 \\ 0 \quad \text{otherwise} \end{cases} \quad (20)$$

$$y_E = S_{ac} - y_0 \quad (21)$$

$$y_R = -y_0 \quad (22)$$

Where: g - Acceleration due to gravity (m/s²); M - Mass of the weight-loaded accumulator (kg); D_{ac} - The diameter of piston of the weight-loaded accumulator (m); F_{cac} – The frictional force between the piston and the cylinder in the weight-loaded accumulator; y is the piston position of accumulator; y_0 is the initial distance between the piston and cap A; y_E is the distance traveled by the piston to fully extend from the initial position; y_R is the distance the piston can travel to fully retract from the initial position; K_{pac} is the penetration coefficient; S_{ac} is the piston stroke of accumulator.

The energy of the hydraulic accumulator can be determined:

$$E_{ac} = \int p_{ac} Q_{ac} dt \quad (23)$$

Where: Q_{ac} - The hydraulic oil flow pushed into the weight-loaded accumulator (m³/s).

$$Q_{ac} = q - q_{vi} \quad (24)$$

$$p_{ac} = p_c - \Delta p - \Delta p_{vi} \quad (25)$$

3.6. Model of a vehicle passing over a speed bump

Assuming that the load force exerted on the speed bump, F_{kt}, remains constant during the time the wheel is in contact with the speed bump; assuming the vehicle speed is constant and the wheel maintains continuous contact with the speed bump, the dwell time of the wheel on the speed bump can be determined by the following expression:

$$T_s = \frac{B}{v_{xe}} (s) \quad (26)$$

Where: T_s - Time for the wheel to pass

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over the speed bump (s); B - Width of the speed bump (m); v_{xe} - Velocity of the vehicle (m/s)

4. RESULTS AND DISCUSSION

From equations 1 to 25, using the Matlab-Simulink program, the EHSSB is modeled.

Table 1. Parameters of the EHSSB:

Parameter of the EHSSB	Value
m - Mass of the speed bump (kg)	80
K – Spring constant (N/m)	10000
B - Width of the speed bump (m)	0,35
v_{xe} - Velocity of the vehicle (m/s)	[1.39; 2.78; 4.15]
i_1 - The transmission ratio from the speed bump to the rod of the hydraulic cylinder	0.2
D_{pt} - Piston diameter (m)	0.05
D_H - Pipe hydraulic diameter (m)	0.0381
L - Pipe geometrical length (m)	3
ν - Fluid kinematic viscosity (m^2/s)	1.8e-05
ρ - Fluid density (kg/m^3)	850
D_{ac} - The diameter of piston of the weight-loaded accumulator (m)	0.3
M - Mass of the weight-loaded accumulator (kg)	981.25

The input parameters for the calculation program are in accordance with Table 1. After entering the parameters into the Matlab-Simulink program, some results are presented in various figures, as shown in Figure 4:

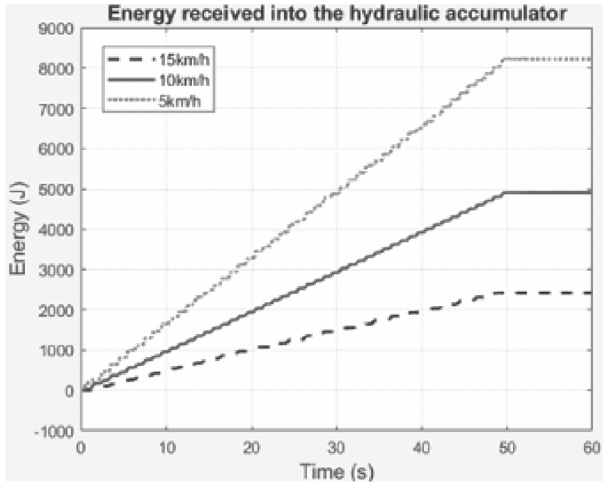

Figure 4. The energy graphs obtained in three cases of vehicle movement
(V_{xe} = 15km/h; 10km/h; 5km/h).

Figure 4 illustrates the energy obtained by the weight-loaded accumulator after applying force to a speed bump 50 times in three cases of vehicle movement with corresponding speeds of (15 km/h, 10 km/h, and 5 km/h). The respective elevations of the obtained energies are 2418 J; 4881 J; and 8220 J. Comparing the three cases and considering the same number of vehicle passes reveals that at slower speeds, the obtained energy is greater.

5. CONCLUSION

The article has successfully developed a model for an energy harvesting system from the speed bump, using a hydraulic accumulator of the gravitational type. Through this model, we can employ it for researching, investigating, and assessing the energy harvesting potential of the speed bump.

The results have demonstrated the energy harvesting capability of the EHSSB system, providing a foundation for the design and fabrication of the EHSSB system in practical applications.

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