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APPLICATION OF SIMULATION RESEARCHES IN DIAGNOSTIC'S OF VEHICLE HYDROPNEUMATIC SUSPENSION

Summary. This paper presents results of simulation researches of changes in technical condition of vehicle hydropneumatic suspension (changes of pressure nitrogen in hydropneumatic sphere which causes changes in gas spring and dumper characteristics). The static load of vehicle has been changed too. The input harmonic signal was used and changes of magnitude for higher range harmonics were analyzed.

ZASTOSOWANIE BADAŃ SYMULACYJNYCH W DIAGNOSTYCE ZAWIESZENIA HYDROPNEUMATYCZNEGO SAMOCHODU OSOBOWEGO

Streszczenie. W pracy przedstawiono wynik badań symulacyjnych dla zmian stanu technicznego zawieszenia hydropneumatycznego (obniżenie wartości ciśnienia azotu w sferze zawieszenia hydropneumatycznego powodującą zmiany w charakterystykach sprężyny gazowej i tłumienia kolumny hydropneumatycznej). W badaniach uwzględniono również zamianę obciążenia pojazdu. Zastosowano wymuszenie harmoniczne i analizowano wartości harmonicznych wyższego rzędu.

1. INTRODUCTION

In hydropneumatic suspension (invented by Citroën and fitted to Citroën cars) elements of conventional suspension: steal spring and shock absorber, were replaced by compressible gas (spring element) and incompressible fluid LHM (Liquide Hydraulique Minéral). Movement of the fluid with wheel travel is usually controlled by an integral dumping device (shock absorber in hydropneumatic suspension).

Fig. 1. Sphere of hydropneumatic suspension
Rys. 1. Sfera zawieszenia hydropneumatycznego

Hydropneumatic suspensions have many advantages. The most important one is constant height of vehicle independently from static load. This kind of suspensions provide high travel comfort because the stiffness of hydropneumatic spring is lower than the stiffness of steal spring [1, 2, 3, 4, 6, 8].

The most common change in technical condition of vehicle hydropneumatic suspension is lowering of the nitrogen mass in the hydropneumatic sphere; the nitrogen is diffused by flexible membrane which separates the nitrogen and the hydraulic fluid. This change causes changes in spring and dumping characteristics. The influence of this change in hydropneumatic suspension was researching by simulation experiment.

2. FRONT MC'PHERSON SUSPENSION MODEL

In vehicles with hydropneumatic suspension typical solution are used: for example front McPherson suspension with adaptation hydropneumatic strut (Citroen BX) [7].

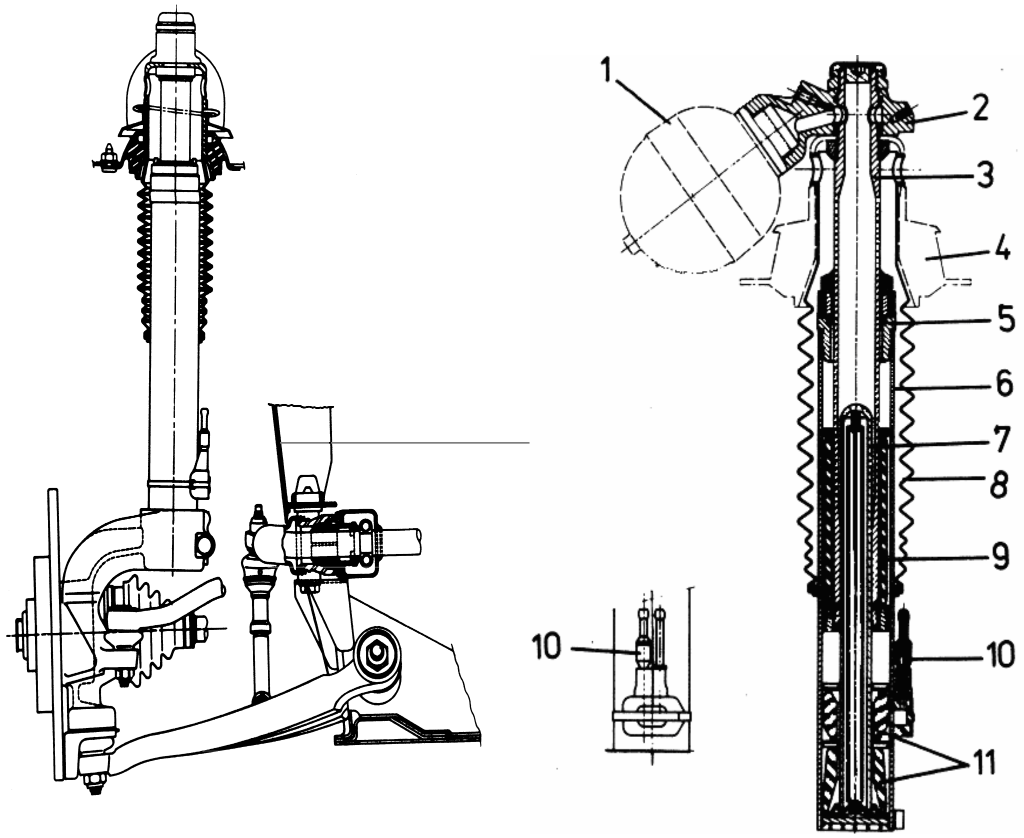


Fig. 2. Hydropneumatic suspension (a) and front hydropneumatic strut of Citroen BX 14
where: 1. Hydropneumatic sphere, 2. Cantilever, 3. Cylinder, 4. Rubber cushion linking hydropneumatic strut and body, 5. Guide, 6. External casing, 7. Piston, 8. Rubber shield, 9. Bumper lower, 10. Check valve, 11. Bumper upper.
Rys. 2. Zawieszenie przednie Citroen BX (a) i przekrój przedniej kolumny hydropneumatycznej (b)

Plane model of McPherson front suspension which takes into account kinematics of suspension, is represented on figure 3.

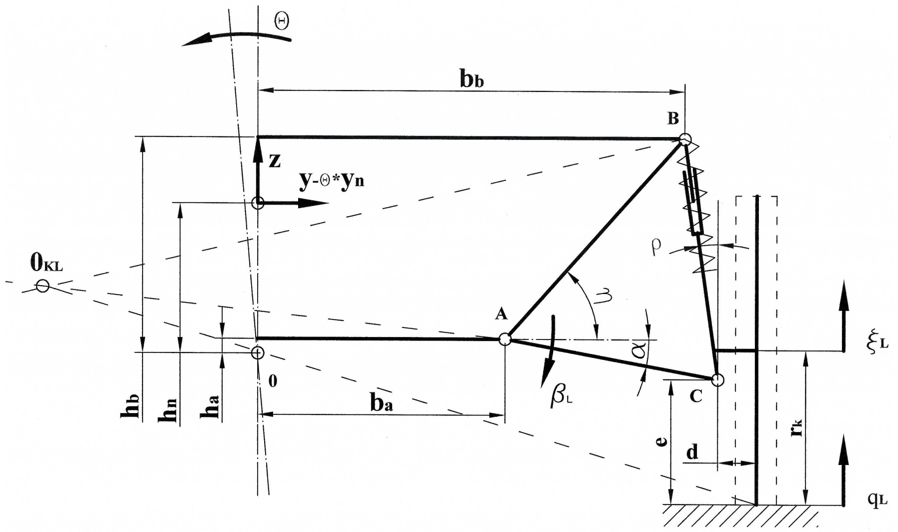


Fig. 3. Plane model of McPherson front suspension
Rys. 3. Model płaski przedniego zawieszenia typu McPherson

Points O_{KL} i O_{KP} are instantaneous pivoting points of wheel (unsprung mass) relative to body (sprung mass). Point O is central pivoting point of body. Position characteristics points of body (b_a b_b h_a h_b h_n) are determined to point O.

This model of McPherson front suspension has five degrees of freedom:
- vertical and lateral movements of body (z, y),
- roll of body θ,
- vertical movements of wheels (ξ_L i ξ_P).

Parameters (b_m c_m u_m v_m b_y c_y g_y w_y) determine the influence of geometrics parameters in independent suspension system on variables spring deflection, velocity of shock absorber elements and angular velocity of wheels and A-arms. These parameters are determined in limited interval of variable generalized coordinates; they are constant and invariable in time. Parameters (c_D r_s r_d) determine the influence of the stabilizer bar on the front suspension.

Stiffens of gas spring and dumping of hydropneumatic strut are determined by nonlinear function F_S and F_A.

Equation of motion are determined by Lagrange method (kinetic energy, potential energy and Rayleigh function are defined).

After transformation the acceleration equations on general form are received:

$$\ddot{y} = \frac{1}{(M+2m)} \cdot \left[(2c_y \cdot m + hn \cdot M)\ddot{\theta} + m \cdot b_y \cdot \left(\ddot{\xi}_L - \ddot{\xi}_P\right)\right] \tag{1}$$

$$\ddot{z} = \frac{1}{\left(M + 2m \cdot b_y^2 + 2m \cdot \rho_{XK} \cdot v_m^2\right)} \cdot \left[\left(\left(m \cdot b_y^2 + m \cdot \rho_{XK}{}^2 v_m^2\right) \cdot \left(\ddot{\xi}_L + \ddot{\xi}_P\right)\right) + 2F_A g_y^2 \left(\dot{\xi}_L + \dot{\xi}_P - \dot{z}\right) + 2F_S g_y^2 \left(\xi_L + \xi_P - z\right)\right] \tag{2}$$

$$\ddot{\theta} = \frac{1}{\left(M\left(\rho_x^2 + hn^2\right) + 2m \cdot c_y^2 + 2m\rho_{XK}^2 u_m^2\right)} \cdot$$

$$\left[\begin{array}{l} \left(M \cdot hn + 2m \cdot c_y\right)\ddot{y} - \left(m \cdot b_y \cdot c_y + m \cdot \rho_{XK}^2 \cdot u_m \cdot v_m\right) \cdot \left(\ddot{\xi}_L - \ddot{\xi}_P\right) + F_A g_y^2 w_y \left(\dot{\xi}_L - \dot{\xi}_P - 2w_y \dot{\theta}\right) \\ + \left(Mg \cdot hn - 4\left(c_y + 1\right)^2 c_D \left(\frac{r_s}{r_d}\right)^2\right)\theta + F_S g_y^2 w_y \left(\xi_L - \xi_P - 2w_y \theta\right) \\ + \left(2b_y \left(c_y + 1\right) c_D \left(\frac{r_s}{r_d}\right)^2\right)\left(\xi_L - \xi_P\right) \end{array}\right] \tag{3}$$

$$\ddot{\xi}_L = \frac{1}{\left(m + mb_y^2 + m\rho_{XK}^2 v_m^2\right)} \cdot$$

$$\left[\begin{array}{l} m\left[-\left(b_y c_y + \rho_{XK}^2 v_m u_m\right)\ddot{\theta} + \left(b_y^2 + \rho_{XK}^2 v_m^2\right) \cdot \ddot{z} + b_y \ddot{y}\right] - k_K \left(\dot{\xi}_L - \dot{q}_L\right) \\ - F_A g_y{}^2 \cdot \left(\dot{\xi}_L - \dot{z} - w_y \cdot \dot{\theta}\right) + \left(2b_y \left(c_y + 1\right) c_D \left(\frac{r_s}{r_d}\right)^2\right) \cdot \theta - F_S g_y^2 \left(\xi_L - z - w_y \theta\right) \\ - c_K \left(\xi_L - q_L\right) - b_y^2 c_D \left(\frac{r_s}{r_d}\right)^2 \left[\xi_L - \xi_P\right] \end{array}\right] \tag{4}$$

$$\ddot{\xi}_P = \frac{1}{\left(m + mb_y^2 + m\rho_{XK}^2 v_m^2\right)} \cdot$$

$$\left[\begin{array}{l} m\left[\left(b_y c_y + \rho_{XK}^2 v_m u_m\right)\ddot{\theta} + \left(b_y^2 + \rho_{XK}^2 v_m^2\right) \cdot \ddot{z} - b_y \ddot{y}\right] - k_K \left(\dot{\xi}_P - \dot{q}_L\right) \\ - F_A g_y{}^2 \cdot \left(\dot{\xi}_P - \dot{z} + w_y \cdot \dot{\theta}\right) - \left(2b_y \left(c_y + 1\right) c_D \left(\frac{r_s}{r_d}\right)^2\right) \cdot \theta - F_S g_y^2 \left(\xi_P - z + w_y \theta\right) \\ - c_K \left(\xi_P - q_L\right) - b_y^2 c_D \left(\frac{r_s}{r_d}\right)^2 \left[\xi_P - \xi_L\right] \end{array}\right] \tag{5}$$

These equations of motion are solved by Simulink (special simulation program in Matlab). This model in Simulink has five blocks describing generalized coordinates ($\xi_L; \xi_P; z; y; \theta$); two blocks k_A i c_S describing nonlinear spring characteristics F_S and nonlinear dumping characteristics F_A and block describing input function.
Parameters of geometric and masses are determined in special text file (m-file); which generates these elements in workspace. In blocks c_S i k_A nonlinear spring and dumping characteristics are determined.

The left wheel was moving (input function). In simulation experiment Runge – Kutta solver with fixed-step was used.

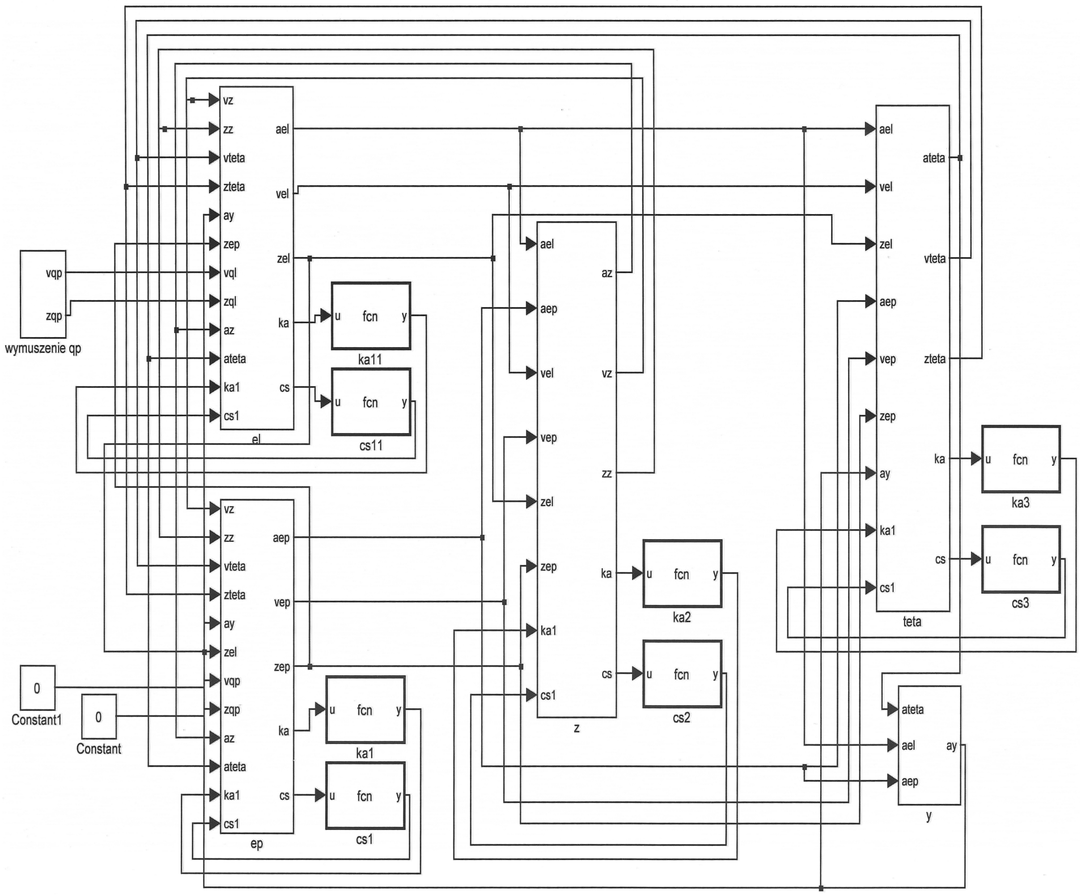


Fig. 4. Model of suspension in Matlab/Simulink solver
Rys. 4. Model zawieszenia w środowisku Matlab/Simulink

This model was verified on a laboratory test stand with kinetic input function. Model verification was made by making use of correlation function between the spectra corresponding to the real object (Citroen BX 14) [5] and the model. High correlation coefficients between the acceleration spectra of wheel and body were determined. The vehicle with hydropneumatic suspension on a test stand is presented on figure 5.

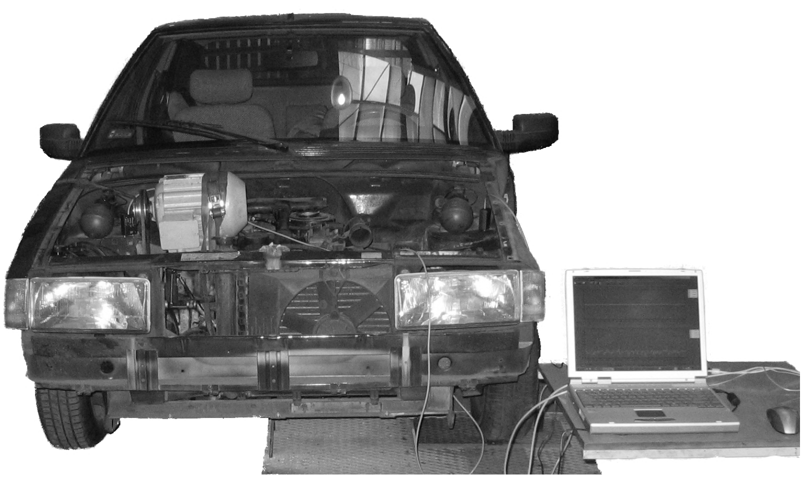
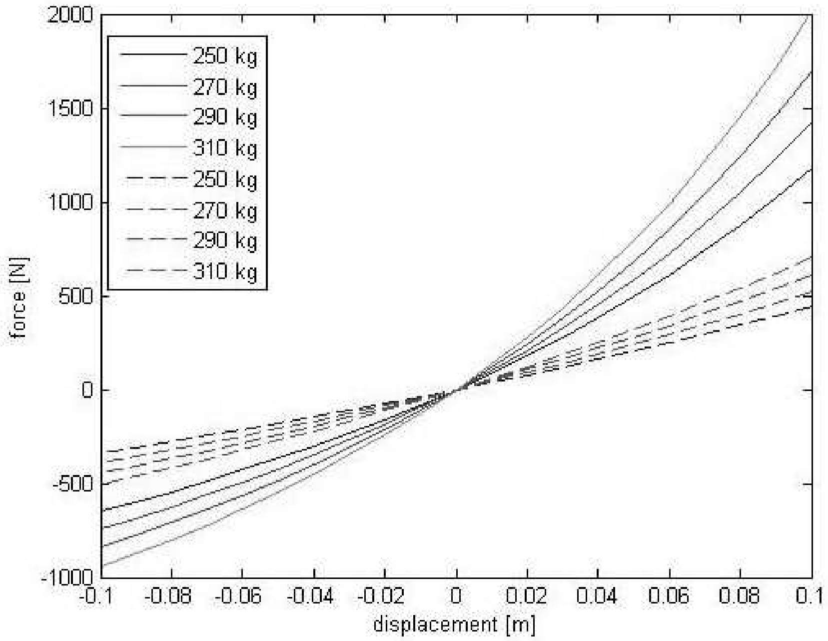


Fig. 5. Car on test stand
Rys. 5. Obiekt badawczy na stanowisku pomiarowym

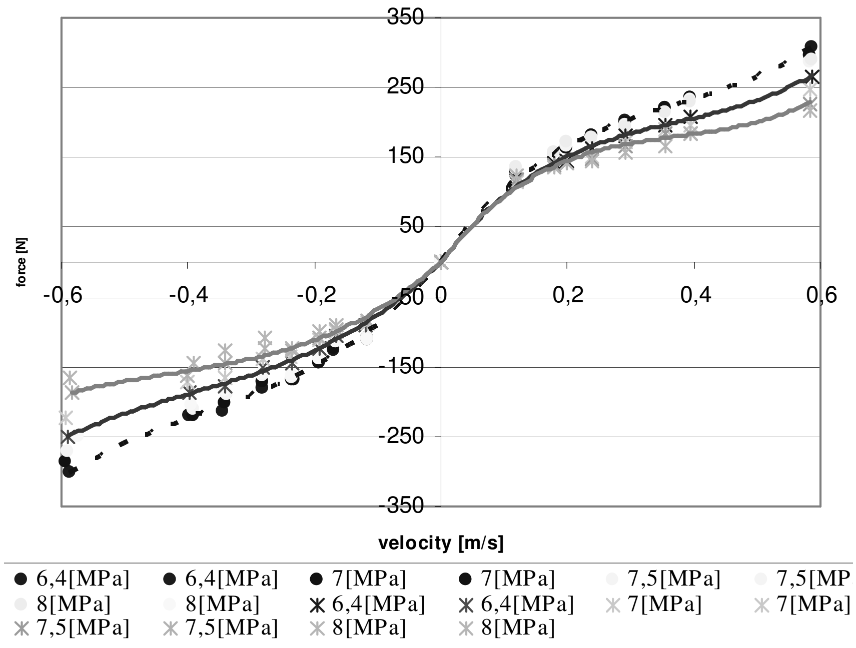
3. CHARACTERISTICS OF SPRING ELEMENT AND DUMPER

The characteristics of spring element (gas spring with constant mass of gas) and dumping for changes of pressure nitrogen in hydropneumatic sphere (nominal pressure p_0=5,5 [MPa] and low pressure p_1=2,5 [MPa]) and changes of static load (250; 270; 290, 310 [kg] for front suspension) are presented on figure 6 and 7.



Pressure in hydropneumatic sphere
p_0=5,5 [MPa] (dashed line)
p=6,4 [MPa]; 250 kg $F(x)=5065\ x^2 + 3805\ x$
p=7 [MPa]; 270 kg $F(x)=6646\ x^2 + 4562\ x$
p=7,5 [MPa]; 290 kg $F(x)=8195\ x^2 + 5247\ x$
p=8 [MPa]; 310kg $F(x)=9973\ x^2 + 5983\ x$
p_1=2,5 [MPa] (continuous line)
p=6,4 [MPa]; 250 kg $F(x)= 25943x^2 + 8744\ x$
p=7 [MPa]; 270 kg $F(x)=34437\ x^2 + 10577\ x$
p=7,5 [MPa]; 290 kg $F(x)=42916\ x^2 + 12266\ x$
p=8 [MPa]; 310kg $F(x)=52830\ x^2 + 14109\ x$

Fig. 6. Characteristics of gas spring: continuous line- p_0=5,5 [MPa]; dashed line - p_0=2,5 [MPa]
Rys. 6. Charakterystyki sprężyny: linia przerywana - p_0=5,5 [MPa]; linia ciągła - p_0=2,5 [MPa]



Pressure in hydropneumatic sphere
p_0=5,5 [MPa](dashed line)
p=6,4 [MPa]; 250 kg p=7 [MPa]; 270 kg p=7,5 [MPa]; 290 kg p=8 [MPa]; 310kg v>0 $F(v) = 2393x^3 - 2673x^2 +1270x$ v<0 $F(v)= 1815x^3 + 2036x^2 + 1084x$
p_0=2,5 [MPa](continuous line)
p=6,4 [MPa]; 250 kg p=7 [MPa]; 270 kg v>0 $F(v) = 2308x^3 - 2593x^2 + 1183x$ v<0 $F(v) = 1392x^3 + 1638x^2 + 905x$
p=7,5 [MPa]; 290 kg p=8 [MPa]; 310kg v>0 $F(v) = 2544x^3 - 2863x^2 + 1197x$ v>0 $F(v) = 1239x^3 + 1594x^2 + 828x$

Fig. 7. Characteristics of dumping: continuous line - p_0=2,5 [MPa]; dashed line - p_0=5,5 [MPa]
Rys. 7. Charakterystyki tłumienia: linia przerywana - p_0=5,5 [MPa]; linia ciągła - p_0=2,5 [MPa]

4. RESULTS OF SIMULATION EXPERIMENTS

In simulation experiments harmonic input function was used. Time history and spectrum of this signal is presented on figure 8. The results of simulation experiment were spectra (FFT) of vertical acceleration of body. Magnitudes of higher range harmonics were analyzed.

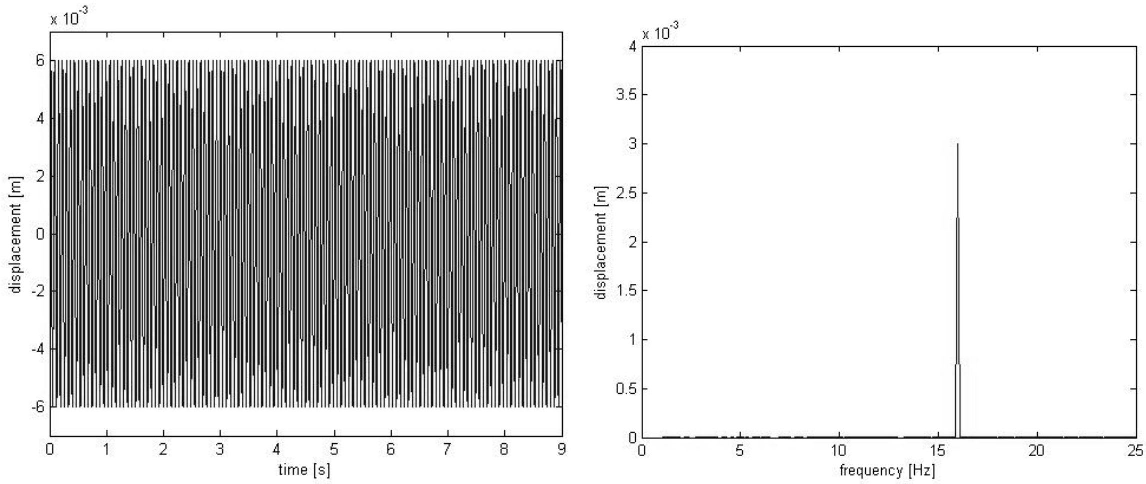


Fig. 8. Input harmonic signal in time and frequency domain
Rys. 8. Przebieg czasowy i widmo wymuszenia sygnałem harmonicznym

Example of spectrum vertical acceleration of body is presented on figure 9 - nonlinear effects in spectrum are represented by higher range harmonics.

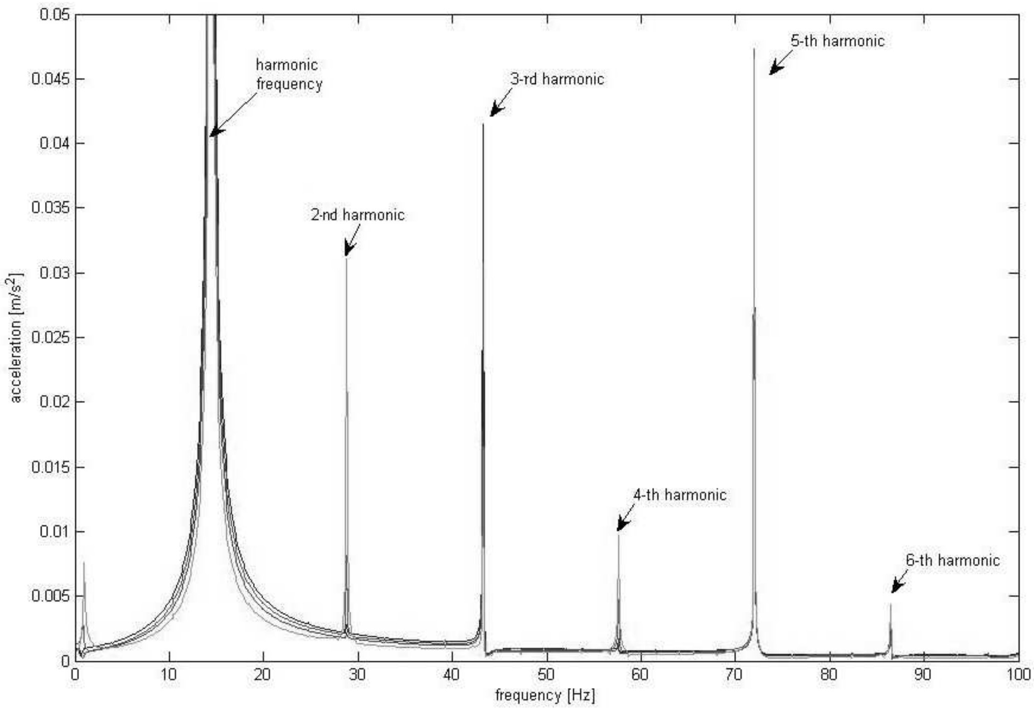


Fig. 9. Example of spectrum vertical acceleration of body
Rys. 9. Przykładowe widmo przyśpieszeń drgań pionowych nadwozia

The decrease of pressure in hydropneumatic sphere and the increase of static load causes increases in magnitude of body acceleration for 2-nd harmonic (fig. 10) and decrease for magnitude of body acceleration for 3-rd harmonic (fig. 11).

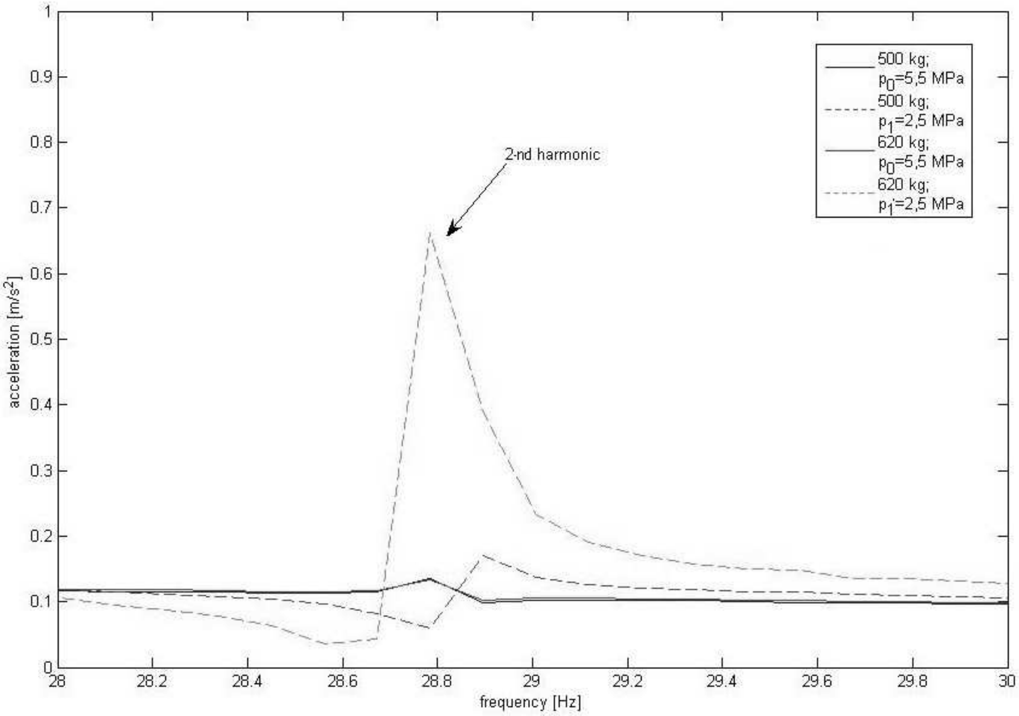


Fig. 10. Changes of magnitude body acceleration for 2-nd harmonic
Rys. 10. Zmiany amplitud przyśpieszeń drgań nadwozia dla 2. harmonicznej

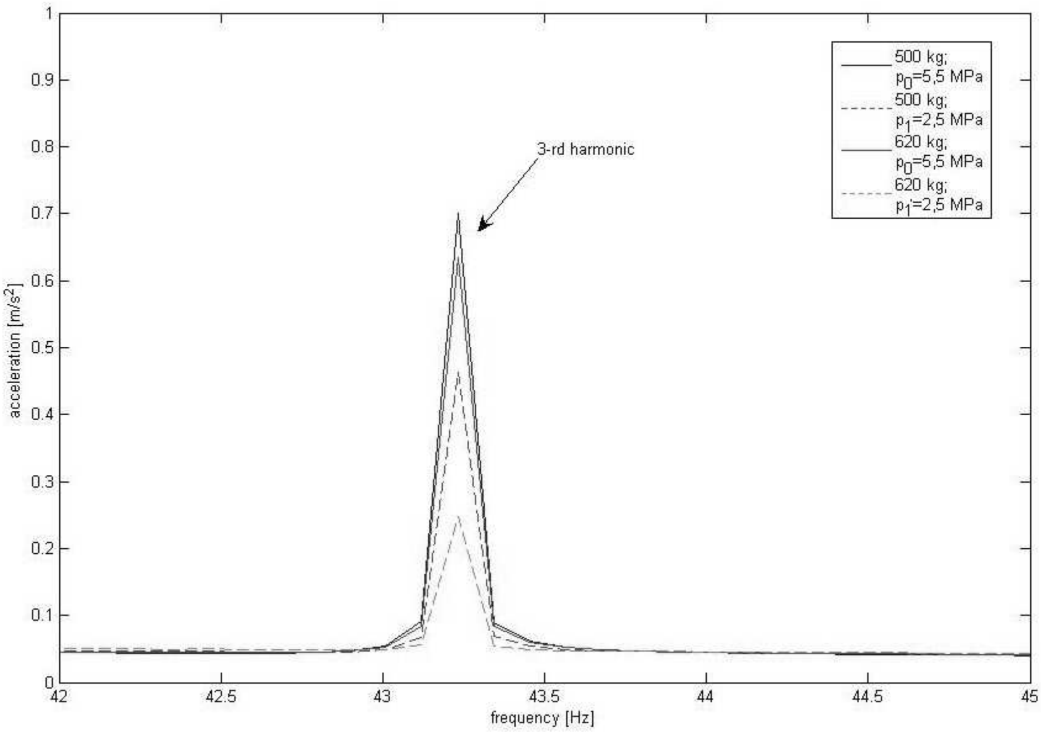


Fig. 11. Changes of magnitude body acceleration for 3-rd harmonic
Rys. 11. Zmiany amplitud przyśpieszeń drgań nadwozia dla 3. harmonicznej

5. SUMMARY

Changes in technical condition in a vehicle hydropneumatic suspension (changes of pressure in hydropneumatic sphere) influence on characteristics of spring element and dumping. Low pressure in hydropneumatic sphere causes the increase of progressive in spring characteristic and decrease of dumping force. This changes causes monotonic changes in magnitude of higher range harmonics (2-nd and 3-rd harmonics). Changes of these parameters can be used in diagnostics of hydropneumatic suspension's technical condition. These results of simulation experiment have to be verified in experiment with real object.

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