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Aspects about bouncing of plough caused by random excitations of the land

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Abstract. *In this paper the author deals aspects about the vertical motion (named bouncing) of a tractor with plough mounted on the rear frame, during displacement over the random excitation surface of the agricultural land. Final results of the simulation process, performed on the model of tractor-plough with 3 degree of freedoms, show the difference between digging depth function as velocity motion and longitudinal profile of the terrain. Thus, the deviation of the plough depth from the reference depth is evaluated.*

Keywords: *tractor, plough, bouncing, random excitation, digging depth*

1. Introduction

This paper deals with dynamic vertical behavior of a plough tractor during the working process when moving on agricultural land. Sometimes, uncontrolled vibrations can occur in the tractor and the wheels sometimes depart from the land. This phenomenon is called "bouncing" and creates to impact dynamics which causes excessive vibration, along with sideslip and poor steering performance which can lead to overturning [1]. Bouncing becomes particularly serious when tractors run on slopes or a field with irregular surface. Due to the motion upon the road irregularities, the structural elements of the tractor are subjected to vertical oscillations, which affect the operation of front and rear suspensions differently [2]. In the same mode, the working accessories that are mounted at the front or rear of the tractor body are affecting [3,4]. The objective of the present study was to analyze the impact dynamics model of the bouncing tractor on an uneven profile of agricultural land using numerical simulation.

2. Mathematical Model

It is considered the movement of the aggregate (tractor with working accessory) as a whole in the vertical plane, when moving over irregularities encountered on agricultural land. Based on equivalent model of a tractor plowing with gauge wheel (fig. 1), its behavior under action of external forces in the vertical longitudinal plane that are appearing to accelerated motion when moving on slope surface should be studied.

Available working accessories are mounted on the base machine (tractor) by suspension linkages using specific mechanisms at the tractor frame. During the technological process, the positions of these mechanisms change insignificantly sometimes, but there may also be situations in which it negatively influences the dynamics of the plowing unit as a whole. For this reason, the following simplifying hypotheses are introduced:

a) during operation the tractor wheels maintain permanent contact (punctual) with the surface of the agricultural land;

b) variation over time of the irregularities of the agricultural land surface is described as a random function;

c) wheels are modeled as identical viscous-elastic elements with linear characteristics (K_{tT}, C_{tT});

d) each wheel of the tractor moves over irregularities with speed v. The amplitudes of the unevenness were noted as follows: with h_1 that corresponding to the front wheels, h_2 to the rear wheels of the tractor and h_4 to the plough wheel.

The study of the vertical oscillations of the tractor will be performed on the equivalent dynamic model and schematic view of this approach is depicted in Figure 2.

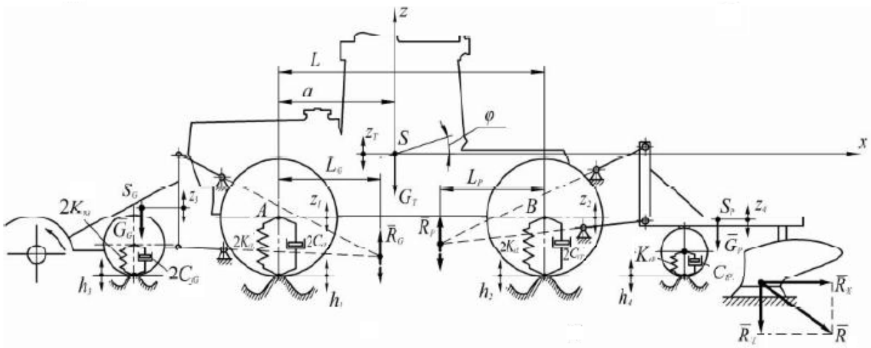


Figure 1. Model for dynamic behavior investigation of the tractor in longitudinal-vertical plane [5].

For only tractor base, the model has two degrees of freedom, with oscillation in the vertical direction (z_T) of the center of mass (S) of the tractor and, respectively, with angular oscillations (φ) of the frame around the same point S. In addition, the plow has a gauge wheel for continuously monitors the contact with the profile of the agricultural land (denoted with h_4), and their dynamic behavior is characterized by stiffness K_{tP} and damping coefficient C_{tP}. The dynamic plough model has a degree of freedom described by moving the center of gravity (S_P) of the equipment in the vertical direction (z_4). The forces acting on the plough are: the weight G_P; the reaction force R_P as a result of the attachment of this equipment to the tractor frame; the component in the vertical direction R_Z of the resistance R at the working tool of the plough. The use of Lagrange equations of the second kind are suitable to describe the motion of the tractor body and, respectively, for the plough mounted on the rear of the tractor [6].

$$\begin{cases} \dfrac{\left[m_T(L-a)^2+J_T\right]}{L^2}\ddot{z}_1+2C_{tT}\dot{z}_1+2K_{tT}z_1+\dfrac{\left[m_Ta(L-a)-J_T\right]}{L^2}\ddot{z}_2=2C_{tT}\dot{h}_1+2K_{tT}h_1+ \\ \qquad +\dfrac{1}{L}\left[R_G(L-L_G)+R_PL_P-G_T(L-a)\right] \\ \dfrac{1}{L^2}\left(m_Ta^2+J_T\right)\ddot{z}_2+2C_{tT}\dot{z}_2+2K_{tT}z_2+\dfrac{\left[m_Ta(L-a)-J_T\right]}{L^2}\ddot{z}_1=2C_{tT}\dot{h}_2+2K_{tT}h_2+ \\ \qquad +\dfrac{1}{L}\left[R_GL_G+R_P(L-L_P)-G_Ta\right] \\ m_p\ddot{z}_4+2C_{tp}\dot{z}_4+2K_{tp}z_4=2C_{tp}\dot{h}_4+2K_{tp}h_4-R_p-G_p-R_z \end{cases} \tag{1}$$

Taking into account all the equations of motion of each subsystem (tractor and plough) a system with three equations is obtained which will be the basis for the numerical simulation of the dynamic behavior of the tractor with plough in vertical plane when moving on an agricultural field with irregular profile.

3. Material and method

In this paper, the Case IH Magnum 340 tractor model was chosen to developing proposed approach. Main parameters of this unit are centralized in the Table 1.

Table 1. Identification model of tractor

Parameter	Value
mass tractor	15 t
mass plough	5 t
distance between tractor axles	6 m
distance between the front axle and the center of gravity	2,2 m
L_P distance for the analyzed case	3 m
R_P reaction force for the analyzed case	6 kN
moment of inertia	10^4 kgm^2
tractor wheel stiffness	10^5 N/m
tractor wheel damping	10^3 Ns/m
plough wheel stiffness	10^6 N/m
plough wheel damping	1,8x10^3 Ns/m

The resistance force of a ploughing plough is [7]:

$$R_z = k_0 ab, \tag{2}$$

where k_0 - specific soil resistance to ploughing on medium soil [daN/cm^2]; a - ploughing depth [cm]; b - working width [cm].

For k_0 = 5000 daN/cm^2, a = 0,2 cm and b = 0,2 cm we obtain digging resistance on vertical direction R_Z = 200 daN. About working velocity, we choose the 2nd gear speed to motion aggregate with plough [2,8]. In this case, the plough resistance to ploughing $R_z = (0{,}2 \ldots 0{,}3)F_t$, taking into account by the thrust F_t developed of the tractor unit [9]. If we considered, in addition, the sliding of the running gears δ having several values (δ = 10-17 %), then the working speed v_W becomes $v_t(1-\delta)$, where v_t represents translation velocity of tractor. Nevertheless, in the considered velocity range, that is within 1,38 and 2,77 m/s (or 5 km/h – 10 km/h), the wheel's rolling resistances can be considered almost constant.

In order to simulate the movement of the tractor under the imposed conditions, the following analytical expression was adopted for the spectral composition of the longitudinal profile of the terrain as a function of the excitation pulsation, namely

$$H(s) = \frac{0{,}88}{10^{-4}s^4 + 3\,10^{-4}s^3 + 12\,10^{-3}s^2 + 0{,}11\,s^1 + 5}, \tag{3}$$

whose graphical representation for the pulsation domain $10^{-1} \ldots 10^2$ rad/s is given in the figure 2.

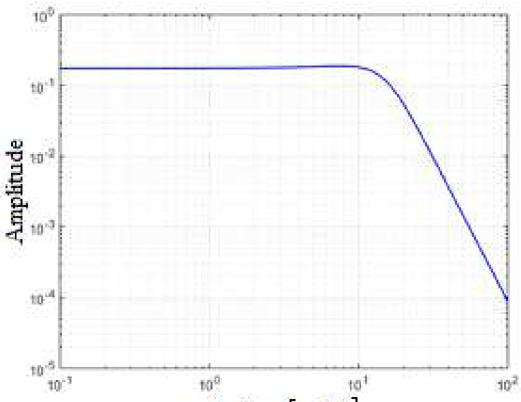


Figure 2. Spectral composition of the longitudinal terrain profile.

Applying the Laplace transform to the differential equations that describe the motion of the tractor-plough system we obtain the following system of algebraic equations

$$\begin{cases}\left(A_{11}s^2 + A_{12}s + A_{13}\right)Z_1 + A_{14}s^2 Z_2 = \left(f_{11}s + f_{12}\right)H_1 + L\left(f_{13}\right)\\ \left(A_{21}s^2 + A_{22}s + A_{23}\right)Z_2 + A_{24}s^2 Z_1 = \left(f_{21}s + f_{22}\right)H_2 + L\left(f_{23}\right),\\ \left(A_{41}s^2 + A_{42}s + A_{43}\right)Z_4 = \left(f_{41}s + f_{42}\right)H_4 + L\left(f_{43}\right)\end{cases} \tag{4}$$

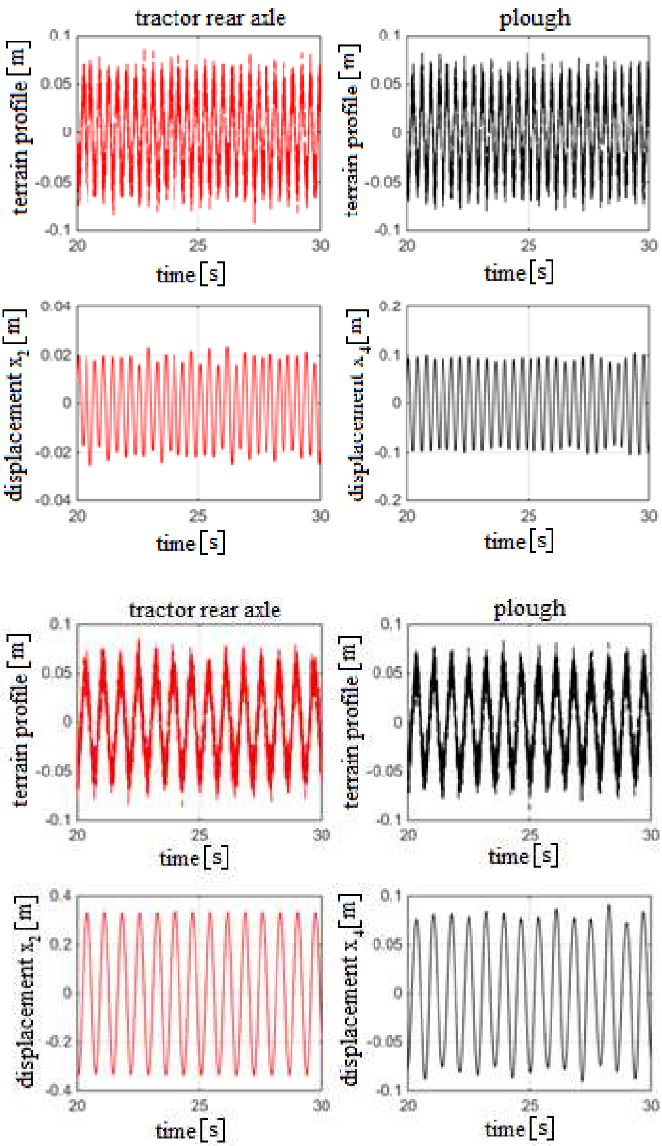
where L(•) represents the Laplace transformation of the dynamic connection functions f_{13}, f_{23}, f_{43}. The evaluation of the transfer functions G_1, G_2, G_4 it was performed through overlapping effects of the two components of the dynamic equation excitations (those generated by the H land profile and those generated by the dynamic connection functions, respectively). The justification of this approach is given by the linearity of the considered model.

The final expressions of the transfer functions for Case IH Magnum 340 tractor model are as follows

$$\begin{gathered} G_1(s) = \frac{-3280s^4 - 320800s^3 + 1{,}362\,10^6 s^2 + 7{,}168\,10^7\ s^1 - 3{,}247\,10^7}{7500s^5 + 30920s^4 + 3{,}099\,10^6 s^3 + 1{,}44\,10^6 s^2 + 7{,}2\,10^7\ s^1}, \\ G_2(s) = \frac{11120s^4 - 1{,}119\,10^6 s^3 + 1{,}383\,10^6 s^2 + 7{,}182\,10^7\ s^1 - 1{,}834\,10^7}{7500s^5 + 30920s^4 + 3{,}099\,10^6 s^3 + 1{,}44\,10^6 s^2 + 7{,}2\,10^7\ s^1}, \\ G_4(s) = \frac{36s^2 + 2\,10^4\ s^1 - 1141}{100s^3 + 36s^2 + 2\,10^4\ s^1}. \end{gathered} \tag{5}$$

4. Evaluation of the response of the tractor with plough on travel on agricultural field

The evaluation of the response functions in the time domain of the plough tractor assembly, when moving on lands with irregular profile, was performed considering the respective system under the action of pseudo-random excitations. The regular longitudinal profile was simulated using a harmonic function, with the period $T_m = 2$ m and the amplitude $h = 0{,}050$ m, this being the deterministic component of the excitation signal. The random component of the signal was obtained by adding a random signal (white noise type) with the signal / noise ratio (denoted S/N) variable in the range 0,1...10. The first value in the considered range means an approximately smooth longitudinal profile, while the second value indicates a profile strongly affected by random components. The numerical analysis of the dynamic behavior of the tractor-plough assembly under the action of the mentioned excitation, was actually performed for two values of the travel speed from the admissible range: 5 km/h and 10 km/h. The results obtained are presented in figures 3 and 4.



a)

b)

Figure 3. The response of the unit tractor - plow for S/N = 10 in the case of: a) v = 10 km/h; b) v = 5 km/h.

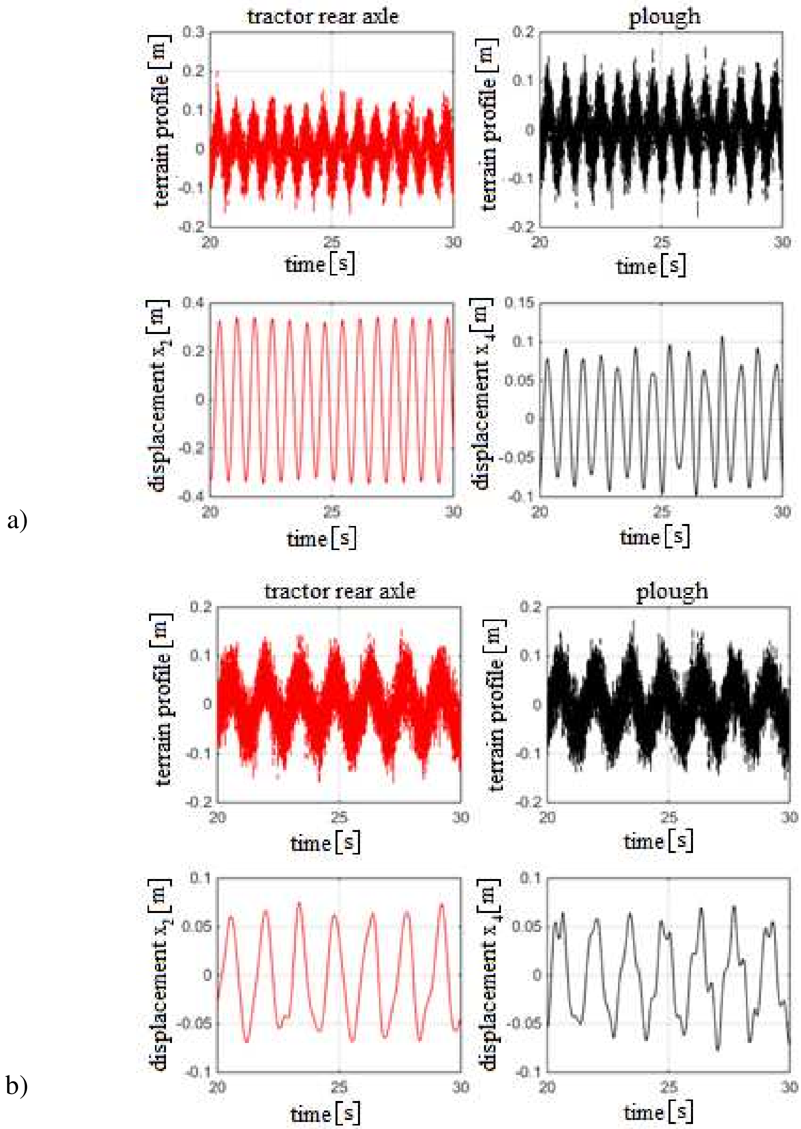


Figure 4. The response of the unit tractor - plow for S/N = 0,1 in the case of:
a) v = 10 km/h; b) v = 5 km/h.

Each set of diagrams in these figures contains the excitation signal for each interaction point of the tractor-plough assembly with the terrain profile (out of phase with the speed of movement), as well as the time response for each degree of freedom considered (the vertical direction of the rear axle and plough axle, respectively). The evaluation of the response of the tractor-plough system allows a comparative analysis of the digging depth of the plow according to the speed of movement and, respectively, the longitudinal profile of the terrain on which the machine moves. The deviation of the digging depth of the plough from the reference depth was evaluated for each case by the difference between the instantaneous value of the excitation at the ground-plow interaction point and the instantaneous value of the vertical displacement of the plow under the dynamic action of the field.

If the reference value is considered h = 0,050 m for maximum amplitude of the land uneven, the maximum percentage values of the deviation from the reference digging depth performed with the tractor (only for rear axle of the tractor and, respectively, for gauge wheel of the plough), in the table 2 are presented.

Table 2. Maximum percentage deviation from the reference digging depth [in %]

ratio S/N	Velocity [km/h]	
	5	10
0,1	296,8	343
10	106,6	147

5. Conclusion

The numerical simulation shows that the developed mathematical model can be further used to study the influence of different constructive and kinematic parameters of the rear-mounted ploughing equipment in order be optimized with the final aim to assess and reduce the oscillations arising during its operation.

The comparative analysis of the results obtained in this study highlights a series of disturbing dynamic evolutions, which manifest themselves on the tractor-plough assembly during the technological work process, with a negative influence on the technological performance in terms of continuous and random variation of the instantaneous digging depth. The results presented in the previous paragraphs lead to the conclusion that in order to obtain the required technological performances, a correlation is necessary between the values of the functional parameters and the effective profile of the land on which the respective activity is carried out. Thus, a speed of movement close to the upper limit of the permissible range can produce, in the conditions of a strongly irregular profile, inadequate deviations from the optimal digging depth, while values of the speed towards the lower limit lead implicitly to a decrease in productivity. Under these conditions, the initial assessment of the state of the running surface of the tractor together with the attached equipment is necessary in order to establish a speed of movement of the machine to ensure an optimum between the deviation from the digging depth and productivity.

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