THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2008

VIRTUAL PROTOTYPE FOR SIMULATION AND ANALYSIS OF TRACTION SYSTEMS IN INTERACTION WITH ROADS

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ABSTRACT

This study deals with numerical simulation of an equipment with full hydrostatic driving system. Based on the clasical mathematical models - single degree of freedom and two degree of freedom models, it was developed a new set of practical simulation models, named SYMTRAX-I, respectivelly SYMTRAX-II, for the technological equipments with integral hydrostatic driving system. With the help of this models it was simulated the kinematic excitation phenomenon generated by the road. The complexity of this analysis consists in the fact that specific dynamic phenomenon appears at the interaction between the system framed from the road, tire wheels drive devices and the equipment insulated on the tire wheels, and the rolling system, with traction transmission and the base machine engine. This paper presents both SYMTRAX-I, and SYMTRAX-II virtual prototypes, the simulation hypothesis, the computational results, and the comparative analysis between the instrumental tests and the simulation results.

KEYWORDS: virtual prototype, simulation, dynamic analysis, traction system

1. Introduction

The traction systems of the automotive technological equipments could be clasified, by the structural point of view, in integral mechanical systems, integral hydraulic systems, or complex hydro-mechanic systems. These characterizations are based on the type of systems composition of solely mechanical components, solely hydrostatic components, or combined mechanical and hydrostatic components. As a function of these, the traction system acquires the specifical dynamic behaviour under the kinematic excitations generated by the rolling way irregularities, and it could be evolved to resonance phenomenon which propagates into the structure of the driving system.

The complexity of this analysis consist by the fact that the previous presented dynamic phenomenon appears at the interaction between the system framed from the road, tire wheels drive devices and the equipment insulated on the tire wheels, and the rolling system, with traction transmission and the base machine engine.

The entire dynamic process has the common element as the rolling drive system, with dynamic characteristics of tires, on which have closed both the vertical direction movement phenomenon of the equipment as a fact of kinematic excitation, and the torsional dynamic charges of traction system.

This paper deals with virtual prototype of an equipment with integral hydrostatic driving system. With the help of this model was simulated the kinematic excitation phenomenon generated by the road, with its irregularities. Based on the single degree of freedom model, it was developed first practical simulation model of the technological equipment with full hydrostatic driving system, named SYMTRAX-I.

Based on the two degree of freedom model, and on the SYMTRAX - I virtual prototype, it was developed a second practical complex simulation model of the technological equipment with full hydrostatic driving system, named SYMTRAX - II.

Futhermore, will be presented these models, the simulation hypothesis, the results, and the comparative analysis between the instrumental tests and the computational results.

In the concluding remarks paragraph it will be also presented the advantages and the disadvantages of SYMTRAX - II compared to the base SYMTRAX - I model.

2. The SYMTRAX models

In the Figure 1 is depicted the basic model of the SYMTRAX-I virtual prototype.

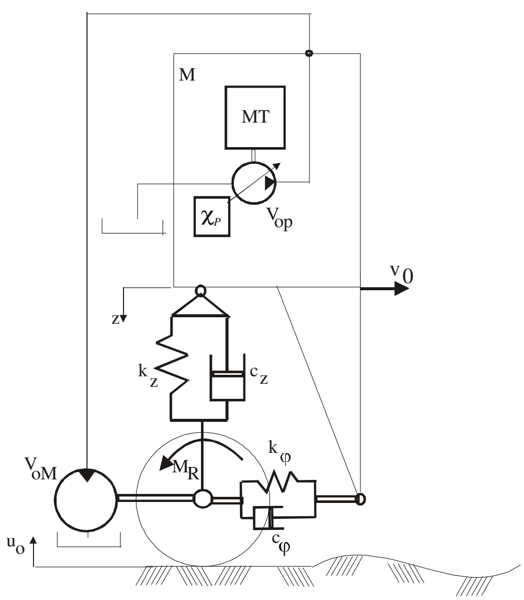

Figure 1. Dynamic model for SYMTRAX-I

The motion equations system for the SYMTRAX-I model is

$$\begin{cases} J_{SP}\dot{\omega}_S + (\chi_P q_P \delta_f + \beta_S)\omega_S + \\ \quad + \chi_P q_P p = \alpha_S \\ (q_M - k^*)\omega_R + \alpha_M p^2 + \alpha_P p + \\ \quad + (\beta_P + \beta_M)\dot{p} = \chi_P q_P \omega_S \\ J_{MR}\dot{\omega}_R - (q_M - k^*)\delta_M(\omega_R - \omega_r)^2 - \\ \quad - (q_M - k^*)p = -M_R \\ J_T\ddot{\varphi}_U - c_\varphi(\dot{\varphi}_R - \dot{\varphi}_U) - k_\varphi(\varphi_R - \varphi_U) = 0 \\ M\ddot{z} + c_z\dot{z} + k_z z = c_z\dot{u} + k_z u \\ u = u_0 \sin(\omega_0 t) \\ M_R = r_D f.M.(g + \ddot{z}) \\ \omega_R = \dot{\varphi}_R \end{cases} \tag{1}$$

The parameters of the virtual prototype have the next expressions

a) the hydrostatic pumps adjustment charateristic

$$\chi_P^* = \frac{N_n}{q_{0P}.\omega_S.p} \tag{2}$$

with

$$\chi_P = \begin{cases} 1 \text{ if } \chi_P^* \geq 1 \\ \chi_P^* \text{ if } \chi_P^* < 1 \text{ and } p \leq 2{,}8.10^7 N/m^2 \\ \chi_{P\min}^* \text{ if } p > 2{,}8.10^7 N/m^2 \end{cases} \tag{3}$$

b) the pulsation of the rolling way irregularities

$$\omega_0 = v_0 / r_D \tag{4}$$

c) the coefficients of rolling resistance have the values presented in Table 1.

Table 1. The rolling resistance coefficients

Rolling resistance coefficient		
puddled ground	moisted sand	asphalt or concrete track
0.03	*0.16*	*0.02*

d) the moment of adherence is given by

$$M_A = r_D \varphi_a.M(g + \ddot{z}) \tag{5}$$

e) the adherence limit condition is

$$M_R < M_A \tag{6}$$

In the Figure 2 is depicted the basic model of the SYMTRAX-II virtual prototype.

The parameters of the virtual prototype have the same significances and values than the SYMTRAX-I model - eqs (2)...(6) and Table 1.

3. The results of computer simulations

The first remark denotes that the mathematical model of the SYMTRAX-I virtual prototype has the expressions (1), and contains five differential equations, which allow computing of the five unknown parameters of the model, namely

- z - the vertical direction displacement of equipment(jumping movement);
- p - the pressure from the hydrostatic driving system;
- ω_S, ω_R, ω_U - the instataneous angular velocities at engine axis, at tire wheel, and respectively, of the whole equipment reduced at the wheel axis.

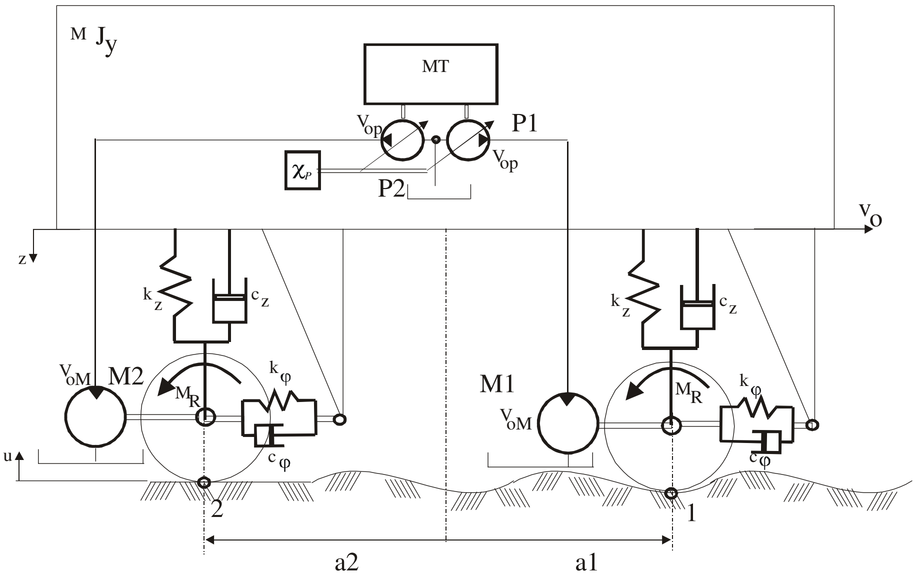

Figure 2. The SYMTRAX - II virtual prototype diagram

The motion equations system for the SYMTRAX-II model is

$$
\begin{cases}
J_{SP}\dot{\omega}_S + (\chi_P q_P \delta_f + \beta_S)\omega_S + \chi_P q_P (p_1 + p_2) = \alpha_S \\
(q_M - k^*)\omega_{R1} + \alpha_M p_1^2 + \alpha_P p_1 + (\beta_P + \beta_M)\dot{p}_1 = \chi_P q_P \omega_S \\
(q_M - k^*)\omega_{R2} + \alpha_M p_2^2 + \alpha_P p_2 + (\beta_P + \beta_M)\dot{p}_2 = \chi_P q_P \omega_S \\
J_{MR}\dot{\omega}_{R1} - (q_M - k^*)\delta_M (\omega_{R1} - \omega_r)^2 - (q_M - k^*) p_1 = -M_{R1} \\
J_{MR}\dot{\omega}_{R2} - (q_M = k^*)\delta_M (\omega_{R2} - \omega_r)^2 - (q_M - k^*) p_2 = -M_{R2} \\
(J_{T1} - J_{T2})\ddot{\varphi}_U - c_\varphi(\dot{\varphi}_{R1} - \dot{\varphi}_U) - k_\varphi(\varphi_{R1} - \varphi_U) + c_\varphi(\dot{\varphi}_{R2} - \dot{\varphi}_U) + k_\varphi(\varphi_{R2} - \varphi_U) = 0 \\
M\ddot{z} + c_z[(\dot{z} - a_1\dot{\varphi}) + (\dot{z} - a_2\dot{\varphi})] + k_z[(z - a_1\varphi) + (z - a_2\varphi)] = c_z(\dot{u}_1 + \dot{u}_2) + k_z(u_1 + u_2) \\
J_{Cy}\ddot{\varphi} + c_z[(a_1\dot{\varphi} - \dot{z})a_1 + (a_2\dot{\varphi} - \dot{z})a_2] + k_z[(a_1\varphi - z)a_1 + (a_2\varphi - z)a_2] = \\
\quad = c_z(a_1\dot{u}_1 + a_2\dot{u}_2) + k_z(a_1 u_1 + a_2 u_2) \\
u_1 = u_{01}\sin(\omega_0 t) \\
u_2 = u_{02}\sin(\omega_0 t + \theta_0) \\
M_{R1} = r_D f.M.(g + \ddot{z} - a_1\ddot{\varphi}) \\
M_{R2} = r_D f.M.(g + \ddot{z} - a_2\ddot{\varphi}) \\
\omega_{R1} = \dot{\varphi}_{R1} \\
\omega_{R2} = \dot{\varphi}_{R2}
\end{cases}
\qquad (7)
$$

The second remark denotes that the mathematical model of the SYMTRAX-II virtual prototype has the expressions (7), and contains eight differential equations, which allow computing of the eight unknown parameters of the model. The differents namely

- φ - the rotational angle of the equipment (rocking movement);
- p_1, p_2 - the pressures from the two energetical lines of hydrostatic driving system;
- ω_{R1}, ω_{R2} - the instataneous angular velocities at engine axis, at front and rear wheels, and respectively, of the whole equipment reduced at the wheel axis.

The expressions (2) and (3) denote the adjustment characteristic of the hydrostatic pump regulator. From these equations results the adjustment factor of the pump displacement flow χ_P, as a function of the pressure in the driving system. Thus that it could be obtained the instantaneous flow rate of the pump.

As a result of the numerical simulation, result the dynamic characteristics of the traction system. Among these, it will be assumed the pressure variation on the driving system, which it was acquired also on the real model.

The real model used for the comparison with the numerical simulation, consists of a wheel frontal loader, with full hydrostatic driving system. This is MMT-45 frontal loader, made by PROMEX SA Braila, Romania.

Figures 3, 4 and 5 show the results of simulations for sundries displacement cases of the proposed equipment.

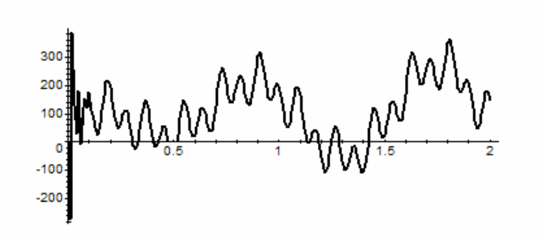

Figure 3. The results of the SYMTRAX-I simulations. The equipment displacement evolution for periodical irregularities of the road and 3 m/s velocity

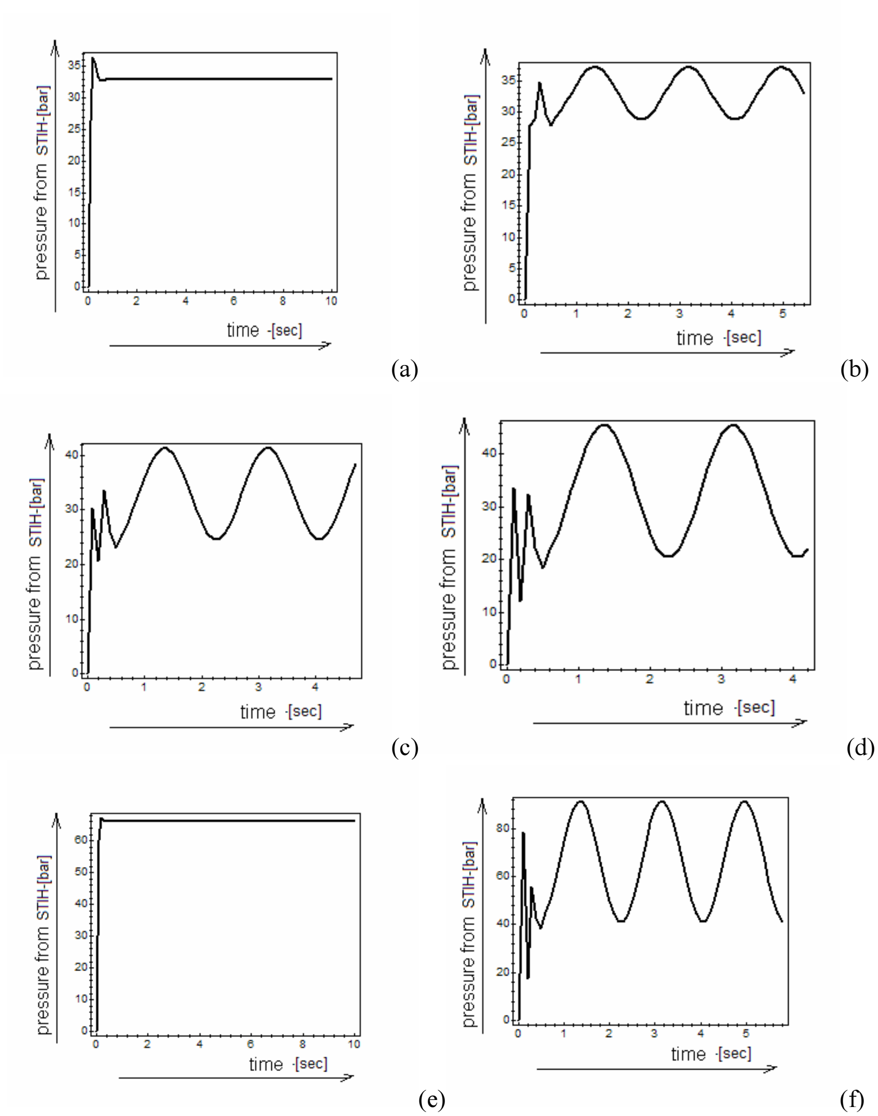

Figure 4. The results of the SYMTRAX-I simulations.
The equipment displacement evolution for harmonical irregularities of the road and 1.5 m/s (5.4 km/h) velocity. (a) no irregularities on road, concrete or asphalt track with $f = 0.02$; (b) harmonical iregs. with 0.1 m elevation, concrete track with $f = 0.02$; (c) harmonical iregs. with 0.2 m elevation, concrete track with $f = 0.02$; (d) harmonical iregs. with 0.3 m elevation, concrete track with $f = 0.02$; (e) no irregularities on road, puddled clay track with $f = 0.03$; (f) harmonical iregs. with 0.3 m elevation, puddled clay track with $f = 0.03$.

For simulations presented in figure 3, the road longitudinal profile is

$$u = 10\sin(6.976\,t) + 5\sin(5\cdot 6.976\,t) + 5\sin(10\cdot 6.976\,t) \quad (8)$$

The road longitudinal profile for simulations in Figure 4 is

$$u = u_{elev}\sin(3.488\,t) \quad (9)$$

where u_{elev} denotes the elevation of the road irregularities.

Based on the comparative analysis between the simulation and the instrumental tests, the numerical results were found in a real dynamic phenomenon.

In figure 6 there were depicted two cases of comparative analysis between the instrumental tests and the numerical simulations.

From numerical simulations correlated with the instrumental tests result, we can mention that the SYMTRAX - II model does not bring any additional informations comparative to the SYMTRAX - I model. But, it complicate much more the numerical analysis procedures.

In figure 7 are depicted the diagrams of pressure variation in hydrostatic driving system circuits - p_1 at front circuit and p_2 at rear circuit - acquired on real model.

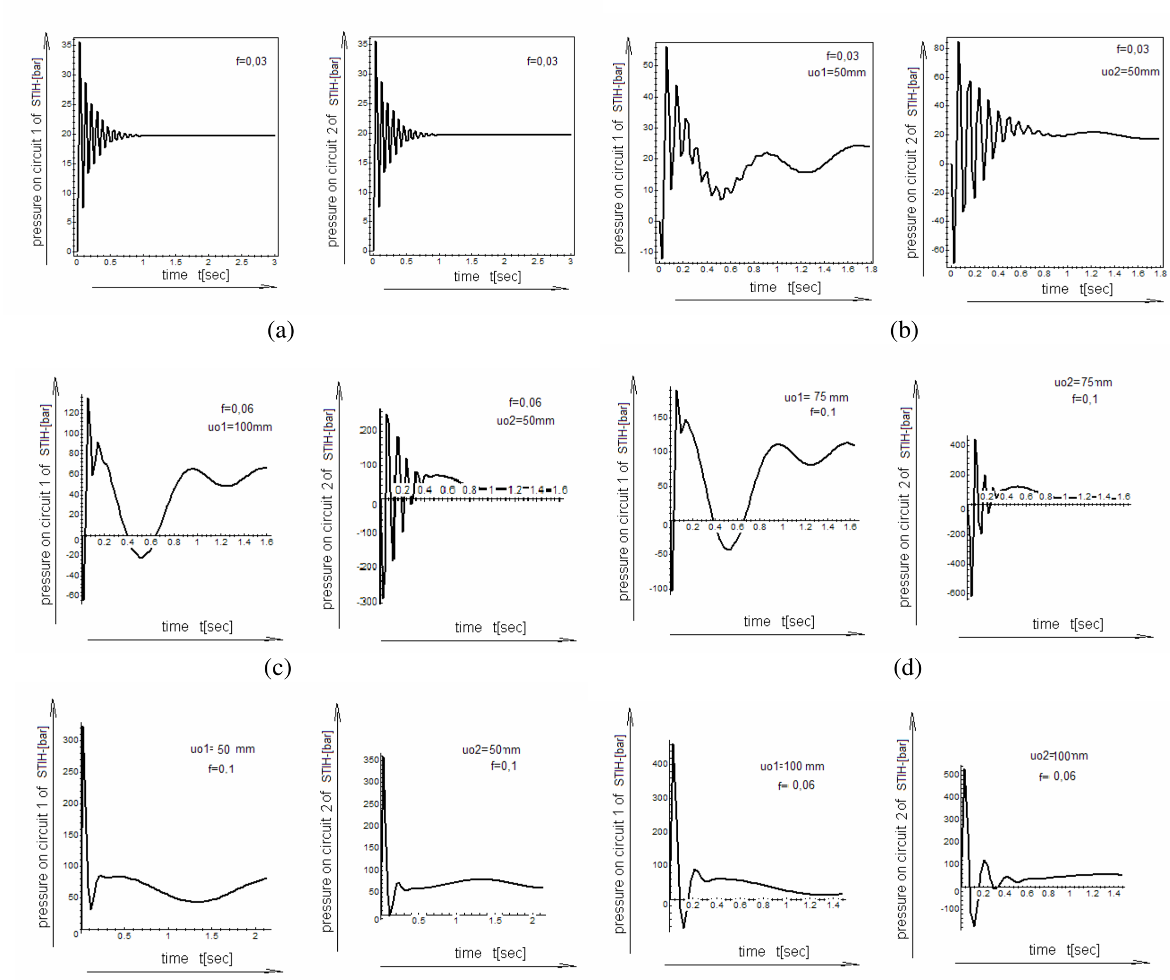

Figure 5. The results of the SYMTRAX-II simulations.
The equipment displacement evolution for harmonical irregularities of the road; puddled clay track with $f = 0.03$; left side - pressure on circuit 1; right side - pressure on circuit 2; (a) no irregularities on road, 1.0 m/s (3.6 km/h) velocity, bucket loaded; (b) harmonical irregs. with 0.05 m elevation, 1.0 m/s (3.6 km/h) velocity, bucket loaded; (c) harmonical irregs. with 0.1 m elevation, 1.5 m/s (5.4 km/h) velocity, bucket loaded; (d) harmonical irregs. with 0.75 m elevation, 1.5 m/s (5.4 km/h) velocity, bucket loaded; (e) harmonical irregs. with 0.05 m elevation, 1.5 m/s (5.4 km/h) velocity, empty bucket; (f) harmonical irregs. with 0.1 m elevation, 1.5 m/s (5.4 km/h) velocity, empty bucket.

4. Concluding Remarks

Based on the analysis of the numerical simulation results, developed on SYMTRAX-I model, it was pointed out the dependences of the pressure for the rolling conditions of the equipment: the type of the road, the elevation and the type of track irregularities, the equipment velocity. It was marked out the fact that the pressure of the equipment driving system follow up the road irregularities.

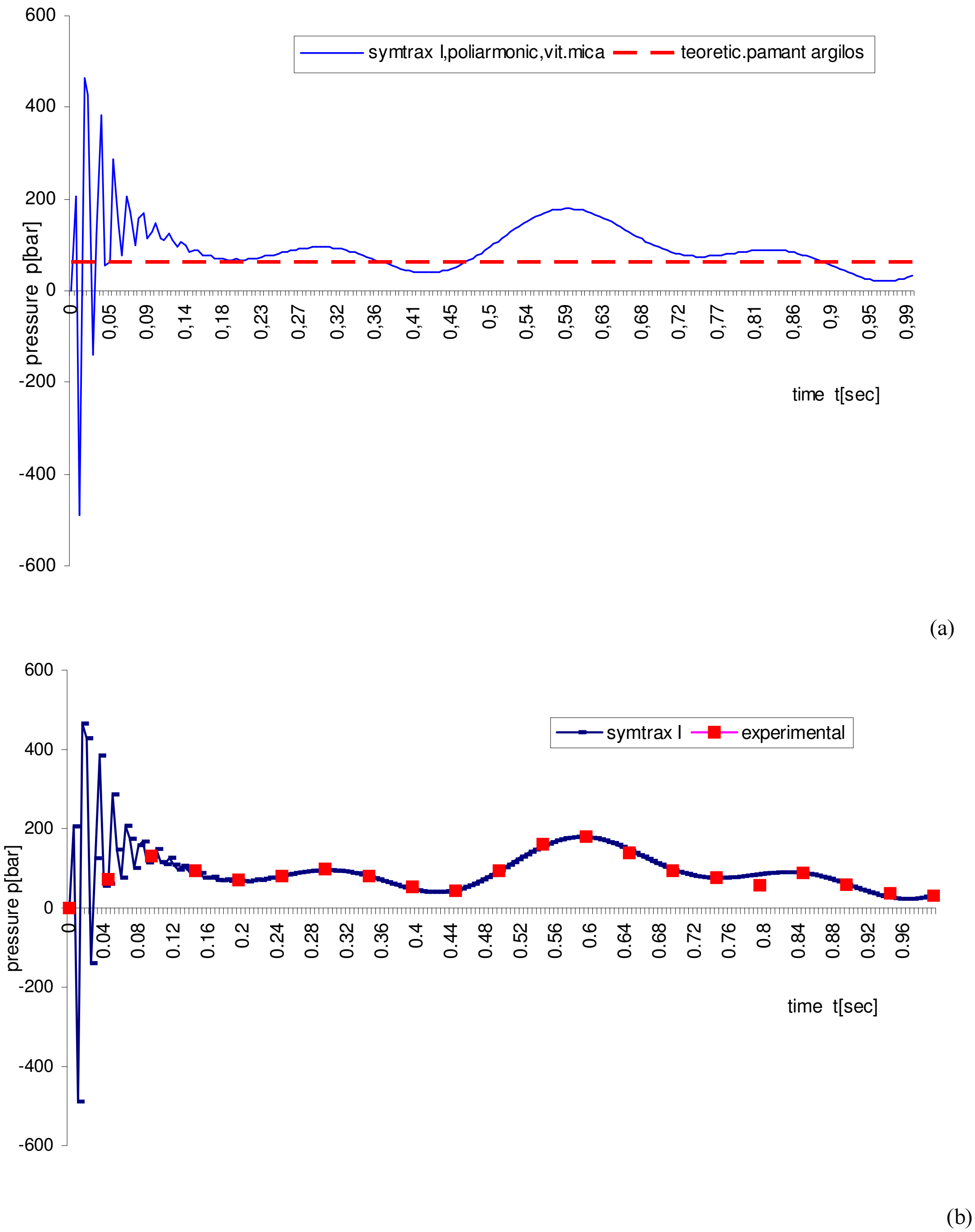

Figure 6. The comparative results for displacement on the puddled clay track with periodical irregularities (a) comparison between the theoretical displacement on direct and flat road without irregularities - red dashed line, and simulated displacement on road with polyharmonic irregularities - thick blue continous line; (b) comparison between simulated displacement on road with polyharmonic irregularities - thick black continous line, and instrumental measured values on real model - red square dots.

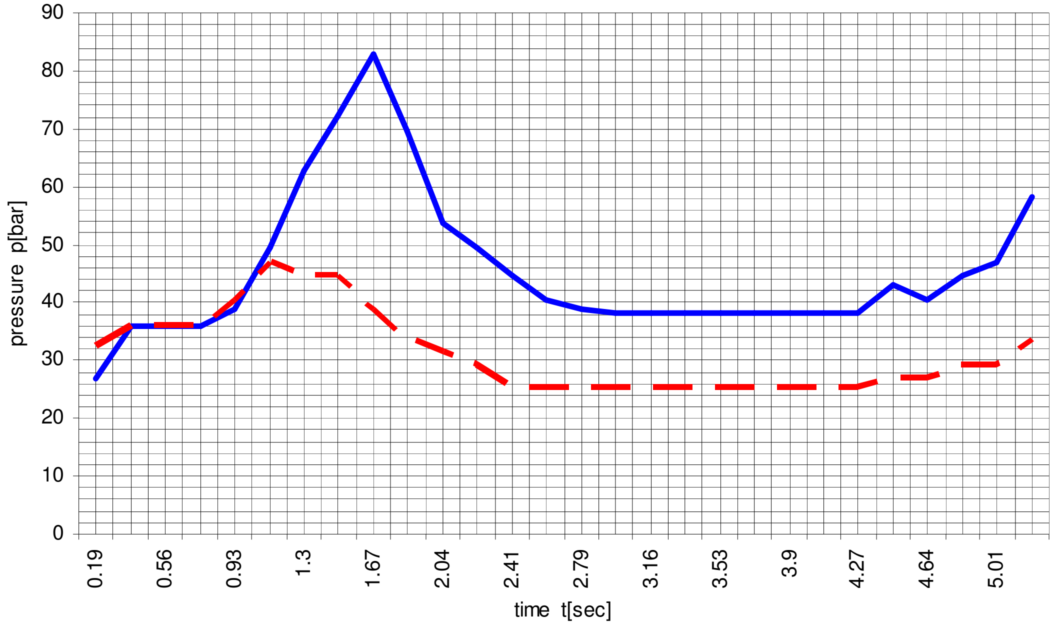

Figure 7. The displacement on a concrete track with a singular irregularity
* the pressure in circuit 1 draw with blue continous line and the pressure in circuit 2 with red dashed line.

It was observed that for the specific conditions supposed for the SYMTRAX-I virtual prototype, even the pressure follows up the irregularities with accuracy, it doesn't match the resonance conditions in the hydrostatic driving system of the equipment. This is due to the fact that natural frequencies of driving system have many differences relative of rolling way pulsations.

For the entire set of excitation frequency values, due to the equipment displacement on the irregular longitudinal profile roads, with technological velocities between 0 and 5.5 km/h, it was not identified the resonance phenomenon, even for the magnitude of the pressure in driving circuit, and for the phases of pressure comparative with the road irregularities.

In case of periodical kinematic excitation (with polyharmonic signals) the pressure follows up the road irregularities, was appear the breaks on linkage with rolling way, respectively the losses of the adherence, especially for high speed displacements (over the technological speed limit).

In case of singular irregularities, the pressure leaps rigorously appear at the moment of subside attack. After this, the dynamic phenomenon acquires speedy damping arround the value that corresponds to the movement on direct and flat road (see Fig. 6).

The SYMTRAX - II virtual prototype does not bring any essential additional information, comparative with the SYMTRAX - I model, concerning the response of the equipment traction system on the kinematic excitation generated by the road irregularities.

In the same time, this second variant of SYMTRAX has a much more complicate motion differential equations system, and of course, needs much more computing resources. These are the motivations of less catching and gainfulyess of this virtual prototype, especially from the designers point of view, who is looking for answers about the behaviour of the traction system at different types and shapes of irregularities of rolling ways. And this was the initial objective of this study.

Because of the complexity of this model, and from the dynamic analysis point of view, SYMTRAX - II was not allowed to obtain new relevant concluding remarks, except for the balanced loaded of the two bridges of equipment. And this was a function of longitudinal position of centre of gravity, and of position and stability of equipment versus base machine, on movement process.

However, based on the analysis of the numerical simulation results, developed on SYMTRAX - II model, it was pointed out the dependences of the pressure on the rolling conditions of the equipment: the type of the road, the elevation and the type of track irregularities, the equipment velocity. It was marked out the fact that the pressure of the equipment driving system follows up the road irregularities. It was observed that for the specific conditions supposed for the SYMTRAX - II virtual prototype, even the pressure follows up the irregularities with accuracy, it doesn't match the resonance conditions in the hydrostatic driving system of the equipment. This is due to the fact that natural frequency of driving system have many differences relative of rolling way pulsations.

With this analysis it was proved that the resonance phenomenon, considered as very imminent at the technological equipments with full hydrostatic driving systems, it is possible to appear only if the designing natural frequencies of the driving system, could be situated nearby the excitation frequencies area of the rolling way, where the machine will be used.

Final concluding remark has to reveal the main importance of these two models in direct and full correspondence with the instrumental tests, even if in this paper these experiments were briefly described. Diagrams from Figures 6 and 7 contain both kind of data: from numerical simulation and from instrumental tests. And, by comparing these two sets of data results a good tunning level of the models with the real behaviour of the technological equipment.

Acknowledgment

Numerical computations have been performed at the *Numerical Simulation of Processes Department*, and the behaviour analysis of the isolation systems have been performed at the *Dynamic Analysis of the Machines and Technical Equipments Department*, both from the *Engineering Faculty of Braila, National Research Center for Machines and Technological Equipments Mechanics*. Instrumental tests and experimental analysis have been performed at the *Research Institute for Construction Equipment and Technologies* - ICECON SA Bucuresti.

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