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ANALITICAL EVALUATION OF THE DYNAMIC PERFORMANCES FOR THE WHEEL LOADER ANALYSIS

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ABSTRACT

In this paper the author propose a physical and mathematical model, useful to analyse the dynamic performances of the wheel loader equipment. It supposed that the evaluation of the natural frequencies constitute a well way to characterised the working characteristic parameters, for some real explatation cases (e.g. natural and aleator obstacles over passing). The proposed analitical way to determine the eigen vectors and values are completed with a numerical modelling with the special softwares packages like MAPLE 7© and MatLAB R12©. This work constitute the first step for the complete analysis procedures of the dynamic behaviour of the wheel loader equipments, in the context of the specific technological process.

1. Introduction

In this paper, the author proposed an phyisical and matematical model for natural frequencies computing for wheel loader supposed with free cross oscillations. For this analisys is supposed the mainly case which the wheel loader have the full bucket and the arm in the transport position. The base machine make the motion strictly in the vertical plane, because of the simetrical construction of the machine compared with the longitudinal plane. Althrough, it was considered that the tires of the same bridge keep equaly deformations.

2. The Moving Equations of the Model

Mathematical proposed model are presented in Figure 1.

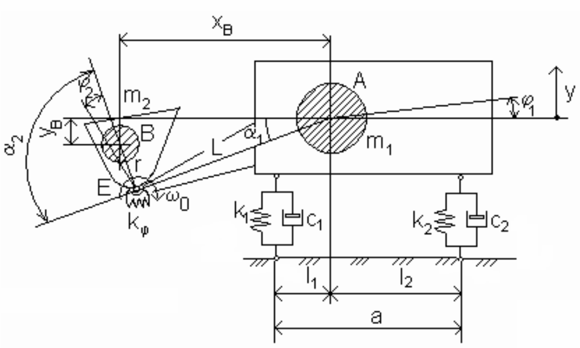

Figure 1. Mathematical model for natural frequencies computing

For writing of the dynamic equations system, for 2DOF model, the author used Lagrange's equations by second order.

$$\frac{d}{dt}\left(\frac{\partial Ec}{\partial \dot{q}_i}\right)+\frac{\partial Ep}{\partial q_i}=0\text{ , i}=\overline{1,3} \qquad (1)$$

where $q_1=y$; $q_2=\varphi_1$; $q_3=\varphi_2$.

The kinetical and the potential energy of the dynamical model have the next expressions

$$E_c=\frac{1}{2}m\dot{y}^2+\frac{1}{2}J_1\dot{\varphi}_1^2+\frac{1}{2}J_{2E}\dot{\varphi}_2^2+\dot{\varphi}_1\dot{\varphi}_2\left(J_2+m_2rb_1\right)- -\dot{\varphi}_1\dot{y}m_2b_2-\dot{\varphi}_2\dot{y}m_2r\cos(\alpha_2-\alpha_1) \qquad (2)$$

$$E_p=\frac{1}{2}k(y+\varphi_1l_2)^2+\frac{1}{2}k(y-\varphi_1l_1)^2+\frac{1}{2}k_\varphi\varphi_2^2 \qquad (3)$$

with

$R^2=L^2+r^2+2Lr\cos\alpha_2$; $b_1=r+L\cos\alpha_2$;

$b_2=L\cos\alpha_1+r\cos(\alpha_2-\alpha_1)$;

$m=m_1+m_2$; m - the system total mass; m_1 - the base machine and the equipment mass; m_2 - the full bucket mass; J_1 - the moment of inertia of m_1; J_2 - the moment of inertia of m_2; $J=J_1+J_2+m_2R^2$ - the moment of inertia of bucket, from *A*; $J_{2E}=J_2+m_2r^2$ - the moment of inertia of bucket, from elastic articulation *E*.

If we derive it and submit the results into the

Eq. (1), we obtaine the differential equations of the 2DOF model

$$\begin{cases} \ddot{y}m-\ddot{\varphi}_1 m_2 b_2-\ddot{\varphi}_2 m_2 r\cos(\alpha_2-\alpha_1)+ \\ \quad +(k_1+k_2)y+(k_2 l_2-k_1 l_1)\varphi_1=0 \\ -\ddot{y}m_2 b_2+\ddot{\varphi}_1 J+\ddot{\varphi}_2(J_2+m_2 r b_1)+ \\ \quad +y(k_2 l_2-k_1 l_1)+\varphi_1\left(k_1 l_1^2+k_2 l_2^2\right)=0 \\ -\ddot{y}m_2 r\cos(\alpha_2-\alpha_1)+\ddot{\varphi}_1(J_2+m_2 r b_1)+ \\ \quad +\ddot{\varphi}_2 J_{2E}+k_\varphi \varphi_2=0 \end{cases} \tag{4}$$

It looking the solutions by the next form

$$\begin{cases} y=A_1\sin(pt+\theta) \\ \varphi_1=A_2\sin(pt+\theta) \\ \varphi_2=A_3\sin(pt+\theta) \end{cases} \tag{5}$$

Next, we obtaine, through derive operation, the velocities and the accelerations expressions

$$\begin{cases} \dot{y}=A_1 p\cos(pt+\theta) \\ \dot{\varphi}_1=A_2 p\cos(pt+\theta) \\ \dot{\varphi}_2=A_3 p\cos(pt+\theta) \end{cases} \tag{6}$$

$$\begin{cases} \ddot{y}=-A_1 p^2\sin(pt+\theta)=-p^2 y \\ \ddot{\varphi}_1=-A_2 p^2\sin(pt+\theta)=-p^2\varphi_1 \\ \ddot{\varphi}_2=-A_3 p^2\sin(pt+\theta)=-p^2\varphi_2 \end{cases} \tag{7}$$

Through substitution into the differential equations system, result

$$\begin{cases} (k_1+k_2-mp^2)y+(k_2 l_2-k_1 l_1+m_2 b_2 p^2)\varphi_1+ \\ \quad +m_2 r p^2\varphi_2\cos(\alpha_2-\alpha_1)=0 \\ (k_2 l_2-k_1 l_1+m_2 b_2 p^2)y+(k_1 l_1^2+k_2 l_2^2-Jp^2)\varphi_1- \\ \quad -p^2(J_2+m_2 r b_1)\varphi_2=0 \\ -m_2 r p^2 y\cos(\alpha_2-\alpha_1)-p^2(J_2+m_2 r b_1)\varphi_1+ \\ \quad +(k_\varphi-J_{2E}p^2)\varphi_2=0 \end{cases} \tag{8}$$

Matrix form for the equations system (2) are

$$\left[D-p^2 I\right]=0 \tag{9}$$

in witch p^2 represent the natural values, and A is the matrix of natural vectors.

The equation of the characteristic matrix D have the expresion

$$\det[D-p^2 I]=0 \tag{10}$$

With the null condition for the determinant system, we could write

$$\begin{vmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{vmatrix}=0$$

where

$$d_{11}=k_1+k_2-mp^2$$

$$d_{22}=k_1 l_1^2+k_2 l_2^2-Jp^2$$

$$d_{33}=k_\varphi-J_{2E}p^2$$

$$d_{12}=d_{21}=k_2 l_2-k_1 l_1+m_2 b_2 p^2$$

$$d_{23}=d_{32}=-(m_2 r b_1+J_2)p^2$$

$$d_{13}=d_{31}=m_2 r p^2\cos(\alpha_2-\alpha_1)$$

The pulsations equation have the next form

$$p^6+C_1 p^4+C_2 p^2+C_3=0 \tag{11}$$

The three order equation, with unknown p^2, could be solved with the next substitution

$$p^2=w-\frac{1}{3}C_1 \tag{12}$$

thus

$$\left(w-\frac{1}{3}C_1\right)^3+C_1\left(w-\frac{1}{3}C_1\right)^2+C_2\left(w-\frac{1}{3}C_1\right)+C_3=0 \tag{13}$$

or

$$w^3-3s_1 w+2n_1=0 \tag{14}$$

where:

$$s_1=\frac{C_1^2}{9}-\frac{C_2}{3} \tag{15}$$

$$n_1=\frac{1}{2}\left(-\frac{C_1}{3}\right)^3+\frac{1}{2}\left(-\frac{C_1}{3}\right)\cdot C_2+\frac{1}{2}C_3 \tag{16}$$

The three order equation have the solutions with the next forms

$$w_1 = \pm 2\sqrt{s_1}\cos\left(\frac{\gamma_1}{3}\right)$$
$$w_2 = \pm 2\sqrt{s_1}\cos\left(60^0 - \frac{\gamma_1}{3}\right) \qquad (17)$$
$$w_3 = \pm 2\sqrt{s_1}\cos\left(60^0 + \frac{\gamma_1}{3}\right)$$

where the upper sign coresponding to the $n_1>0$ case, and the lower sing coresponding to $n_1<0$ case. The γ_1 angle is obtained with formula

$$\cos\gamma_1 = \frac{|n_1|}{s_1\sqrt{s_1}} \qquad (18)$$

So, the natural values could written

$$p_1^2 = w_1 - \frac{C_1}{3}$$
$$p_2^2 = w_2 - \frac{C_1}{3} \qquad (19)$$
$$p_3^2 = w_3 - \frac{C_1}{3}$$

The general solution of the moving differential equations result like a composition of the three motions, and could be determined using the numerical methods.

$$z = A_1\sin(p_1t+\Psi_1) + A_2\sin(p_2t+\Psi_2) + A_3\sin(p_3t+\Psi_3)$$
$$\varphi_1 = k_{1B}A_1\sin(p_1t+\Psi_1) + k_{2B}A_2\sin(p_2t+\Psi_2) + k_{3B}A_3\sin(p_3t+\Psi_3) \qquad (20)$$
$$\varphi_2 = k_{1C}A_1\sin(p_1t+\Psi_1) + k_{2C}A_2\sin(p_2t+\Psi_2) + k_{3C}A_3\sin(p_3t+\Psi_3)$$

The shape of the three natural vibration modes could be computed by evaluation of the A_{11}, A_{12} si A_{13} constants, for the p_1, A_{21}, A_{22} si A_{23} constants, for the p_2, and A_{31}, A_{32} si A_{33} constants, for the p_3.

The A_{1k} (k=1,2,3) coefficients could be computed with the initial conditions for the three vibration modes:

at the t=0 $\Rightarrow \begin{cases} y_0 = 0 \\ \varphi_{10} = 0 \\ \varphi_{20} = 0 \end{cases}$ si $\begin{cases} y_0 = 0.1 \\ \dot{\varphi}_{10} = 0 \\ \dot{\varphi}_{20} = 0 \end{cases}$

3. The Dynamical Behaviour of the Model

The numerical simulation of the dynamic behaviour of the model was realised in the numerical computing software package MAPLE 7©, and the frequency analysis was completed into the MatLAB R12© software.

The analysed case was realised from the real equipment type JCB 413 wheel loader, with the next characteristic values

l_1=0.8m; l_2=1.2m; r=0,350m; L=2,5 m; R=7,6m; b_1=2,11m; b_2=2,5m; m_1=4000 kg; m_2=1500 kg; $\alpha_1=30^0$; $\alpha_2=45^0$; J_1=2500 kgm^2; J_2=500 kgm^2; J=14415 kgm^2; J_{2E}=683,75 kgm^2; k1=k_2=4x10^{5}Nm; k_φ =4x10^{8}Nm/rad.

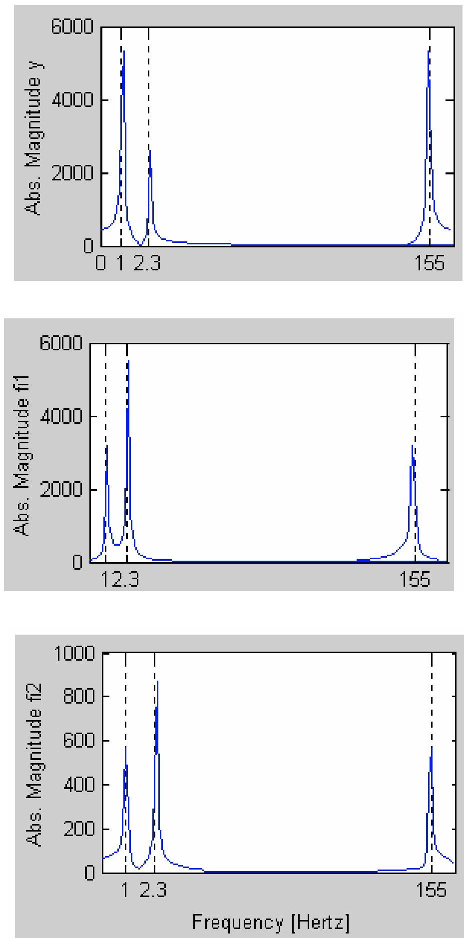

Figure 2. Amplitude spectrum

Making the necessary substitution, we obtaine the natural values

p_1 = 6.76 rad/s;
p_2 = 16.36 rad/s;
p_3 = 973.32 rad/s.

and the natural frequencies are

f_1 = 1 Hz;

$f_2 = 2.3\ Hz;$
$f_3 = 155\ Hz.$

We observe that the obtained values are positives and reals, which means that the mainly system composed by the base machine and the working equipment, have three pulsations which depends only by the system parameters, not for the initial conditions.

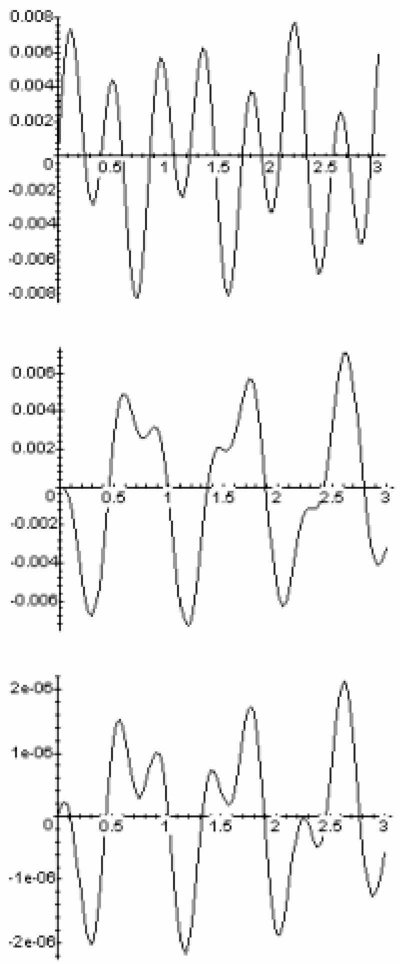

Figure 3. The dynamic model response a) for y; b) for φ_1; c) for φ_2.

4.Concluding Remarks

The knowledge of the natural frequencies values of the wheel loader is very useful to the specialists, engineers and designers.

Into the different working phases of the technological process appear different disturbing factors, which induced into the metallic structure of the base machine and working equipment, the aleator vibrations - e.g. the obstacle over passing process appear into the machine structure like a vibratory phenomenon, with a less or more large spectrum.

If the natural frequencies of the machine are finded into the disturbation spectrum, then appear the resonance phenomenon, which could produced the total or partial brakes into the sub-ensembles links of the machine.

In conclusion, it must be protect the equipment of this unpleasant working situations through an right design of the base machine and equipment.

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