On Nonlinear Dynamics of Dragline Bucket Subjected to Flexible Linkages

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Abstract: - In this paper, the oscillatory motion of the dragline loaded bucket it was highlighted. Hence, the authors proposed a new computational model useful for study of the nonlinear dynamics of the bucket. The linkage of the bucket, consist on hoist rope, it was modelled as flexible element. Hereby, the hoist rope – bucket system provides the pendulum movement of the bucket on horizontal direction, and linear oscillations such as single degree of freedom vibratory system on vertical direction. The numerical simulations, implemented in MAPLE software, show that the trajectory of the mass centre of the bucket is directly influenced by the each structural element motion which compose the proposed model.

Keywords: - dragline, bucket, flexible linkage, oscillation, dynamics.

1. INTRODUCTION

On the site, in embankments works, the dragline are used for excavation and loading ground in the hauling units. Typically construction of this technological equipment has a base machine (excavator or crane), a long boom and one large bucket (Figure 1).

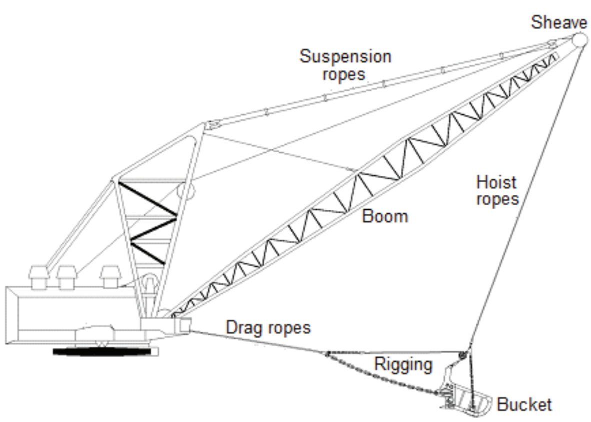

Figure 1. Schematic view of the dragline [5]
1. base machine; 2. boom; 3. bucket; 4. pulley; 5. suspension cables; 6. hoist cables; 7. drag cables; 8. rigging chain.

The bucket is suspended from a boom using wire ropes and it maneuvering is assured by more cables and chains. The dragline rigging mechanism contains three systems with different functions on the bucket motion: hoisting, dragging, and dumping system.

The working cycle of dragline is started by the bringing of the empty bucket to the digging position, lowered and dragged along the material surface until the bucket will be charged. After the excavation operation, through rotating boom around the dragline house, the bucket becomes over the truck and follows charging it.

For the dynamics study of the bucket rigging there is considerable literature model [2],[3],[4],[6]. Various approaches for study of the bucket instability have been proposed using the pendulum model. Ridley et al. [10] implemented a method useful for the control of angular acceleration of the bucket to perturbation factors action as drag-rope velocity and additional drag-rope load. Corke et al. [1] established an algorithm for stabilizing a swinging load, based on measurements of the load position. McInnes & Meehan [7] have studied the dynamics of the bucket swing motion during dragline house slewing. Meehan & Austin [8] investigated chaotic instabilities of the dragline bucket swing.

This paper has focused on the modeling and simulation of the loaded bucket motion using a new model derived from the pendulum model and completed with a flexible linkage consisting of the drag cable.

2. COMPUTATIONAL MODEL FOR DYNAMIC BEHAVIOUR OF THE BUCKET

Schematic diagram in Figure 2 presents a simplified mechanical model developed for behaviour analysis of the bucket subjected to both hoist and drag cables dynamic influences.

The bucket was simulated by a rigid body with mass m on the center of gravity (point D) and moment of inertia J relative to its articulation point on the boom (point B). Onto schematic model in Fig.2, with dashed line was depicted the equilibrium position, and with continuous line a certain transitory position. The dragline boom has a simpler graphical representation, without any additional elements, because it does not a significant part of proposed model.

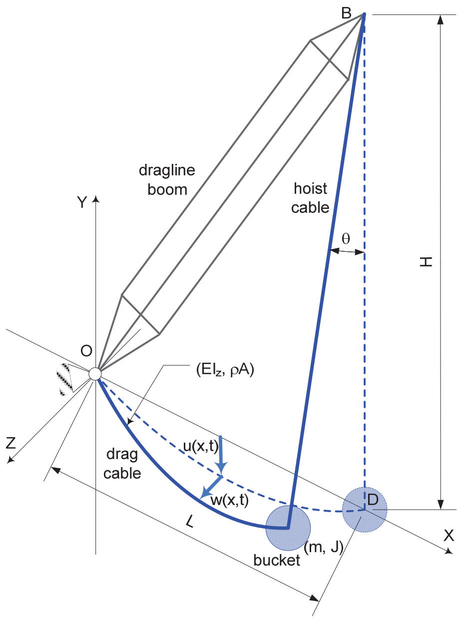

Figure 2. The mechanical model intended for dynamic analysis of the drag cable – bucket – hoist cable system.

The main hypothesis based on this computational model has been developed contain some simplifications in order to allow reducing the total number of degree of freedom and to enable proper exploitation of the numerical methods (in the sense of the restrictions for the number of the independent variables) used to solve the mathematical model:

- The drag rope has both ends with the same elevation ($y = 0$ in global coordinates system);
- The drag rope was supposed to be inextensible, thus that it provides only transversal vibration;
- The hoist rope has tensile properties under longitudinal stress, but these properties were compiled into the k_{ev} parameter. Hereby, the hoist rope – bucket system provides the pendulum movement of the bucket on horizontal direction, and linear oscillations such as single degree of freedom vibratory system on vertical direction;
- The equivalent rigidity of the bucket – hoist cable – dragline boom system on vertical direction contains both the longitudinal rigidity of the hoist cable, and the bending rigidity of the dragline boom system (including the brace system);
- The external forces which lead to transitory dynamics of this system results from the final braking regime of the dragline corresponds to the vertical rotational movement (swinging motion) around the OY axis, between the digging-loading point and the unloading point. Hereby, the inertia of the bucket induces both the balance movement on the horizontal direction, and respectively the initial tensile deformation into the hoist cable on the vertical direction;
- Even if the hoist rope acquire deformations during the dynamic simulation it was supposed to have H = const. length into the pendulum model, because the vibration magnitude provides very small values comparative with the rope length and the corresponding additional term involve neglecting changes in pendulum dynamics.

The effects of the dragline boom onto system dynamics has neglected because it was supposed to have only rigid body behaviour and its stiffness having higher values comparative with the other elements embedded into the model.

3. DIFFERENTIALLE EQUATIONS OF THE BUCKET MOTION

The mathematical model used for simulate the system dynamics contains both partial differential equations - PDE (in order to simulate the transversal oscillations in vertical and horizontal directions of the drag rope), and ordinary differential equations - ODE (in order to simulate the vertical and horizontal oscillations of the bucket – hoist cable system), as follows:

$$EI_z \frac{\partial^4 u(x,t)}{\partial x^4} + \rho A \frac{\partial^2 u(x,t)}{\partial t^2} + c_b \frac{\partial u(x,t)}{\partial t} = q_{oy}(x), \quad (1)$$

$$EI_z \frac{\partial^4 w(x,t)}{\partial x^4} + \rho A \frac{\partial^2 w(x,t)}{\partial t^2} + c_b \frac{\partial w(x,t)}{\partial t} = q_{oz}(x), \quad (2)$$

$$J \frac{d^2\theta(t)}{dt^2} + mgH \sin(\theta) = \\ = EI_z H \left[\left. \frac{\partial^3 u(x,t)}{\partial x^3} \right|_{x=L} \sin(\theta) + \left. \frac{\partial^3 w(x,t)}{\partial x^3} \right|_{x=L} \cos(\theta) \right], \quad (3)$$

$$q_{oy}(x) = \rho A g + m \left. \frac{d^2 u(x,t)}{dt^2} \right|_{x=L}, \quad (4)$$

$$q_{oz}(x) = m\left.\frac{d^2 w(x,t)}{dt^2}\right|_{x=L}, \tag{5}$$

with following initial conditions

$$\begin{cases} u(x,0)=0; \dfrac{\partial}{\partial t}u(x,0)=0; \\ w(x,0)=0; \dfrac{\partial}{\partial t}w(x,0)=0; \end{cases} \tag{6}$$

and boundary conditions for the vertical movement of drag cable

$$\begin{cases} u(x,t)\big|_{x=0}=0 \\ \left.\dfrac{\partial^2 u(x,t)}{\partial x^2}\right|_{x=0,L}=0 \\ EI_z\left.\dfrac{\partial^3 u(x,t)}{\partial x^3}\right|_{x=L}=k_{ev}u(x,t)\big|_{x=L} \end{cases}, \tag{7}$$

and for the horizontal movement respectively

$$\begin{cases} w(x,t)\big|_{x=0}=0 \\ \left.\dfrac{\partial^2 w(x,t)}{\partial x^2}\right|_{x=0,L}=0 \\ w(x,t)\big|_{x=L}=H\sin(\theta) \end{cases}. \tag{8}$$

The parameters in differential equations system have following significations:

- $u(x,t)$, $w(x,t)$ - vertical and horizontal motion of drag cable;
- $\theta(t)$ - independent coordinate of the pendulum;
- H - height of the dragline boom (the length of the hoist cable or the length of the pendulum into the model);
- L - length of the drag cable;
- EI_z - transversal rigidity of the drag cable;
- ρA - unitary mass of the drag cable;
- k_{ev} - equivalent rigidity (on vertical direction) of the bucket - hoist cable - boom system;
- m,J - mass and the moment of inertia of the bucket;
- c_b - specific transversal damping coefficient of the drag cable;
- g - gravity acceleration.

4. SIMULATION OF THE BUCKET OSCILATIONS

The differential equations of the model (Eqs.1-5) are solved by using numerical methods that are implemented in MAPLE software [9].The influences between the pendulum system oscillatory evolution and the drag cable movements has simulated in terms of inertia (into both the PDE and ODE) and through some restrictions imposed on the boundary conditions. For numerical computations it was supposed that angular movement – denoted by θ coordinate – acquires very small values.

Numerical application was developed based on the small dragline characteristics. The parameters of proposed model acquire following values: EI_z = 26388.6 Nm^2, L = 60 m, k_{ev} = 1.32 MNm^{-1}, c_b =10 Nsm^{-1}, m = 6000 kg, ρA = 8 kgm^{-1}, H = 35 m.

In Figures 3 and 4 were depicted the diagrams obtained for the vertical and respectively the horizontal displacement evolution of the bucket during the analysis time.

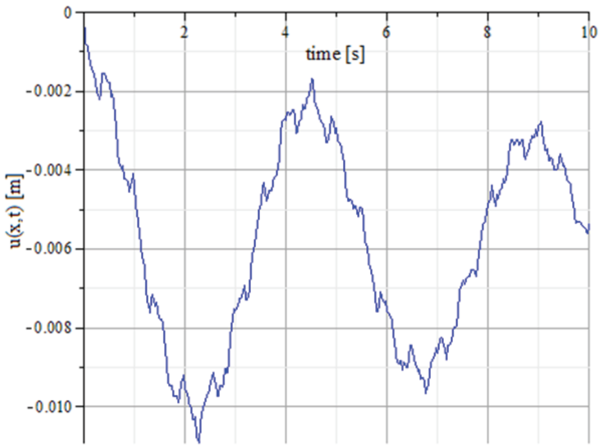

Figure 3. The evolution of vertical displacement of the bucket during the analysis time.

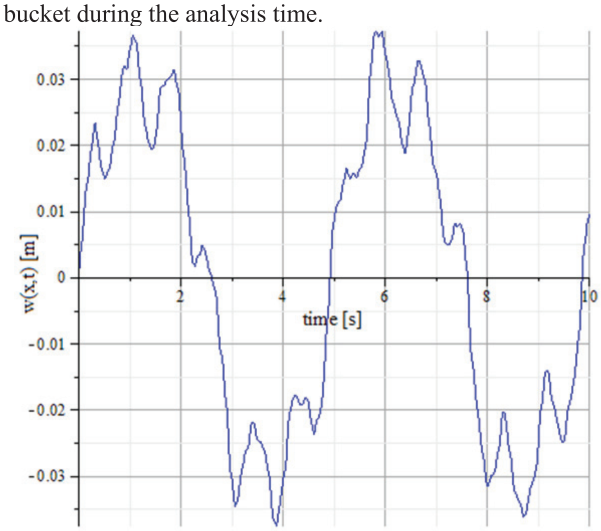

Figure 4. The evolution of horizontal displacement of the bucket during the analysis time.

Comparative analysis of the graphs in Fig. 3 and 4 dignify the influences and cross-correlations between dynamic evolutions of the drag rope and the hoist cable respectively.

The numerical simulations show that the magnitude modulations of both signals put into the evidence the direct influences of each structural element motion against the other. Hereby, it was validate the initial goal of this research means that the analysis of each simple structural component of the system provide wrong results in the sense of diminished transitory state and reduced vibration magnitude.

The timed motion of the center of gravity of the bucket was depicted in Figure 5.

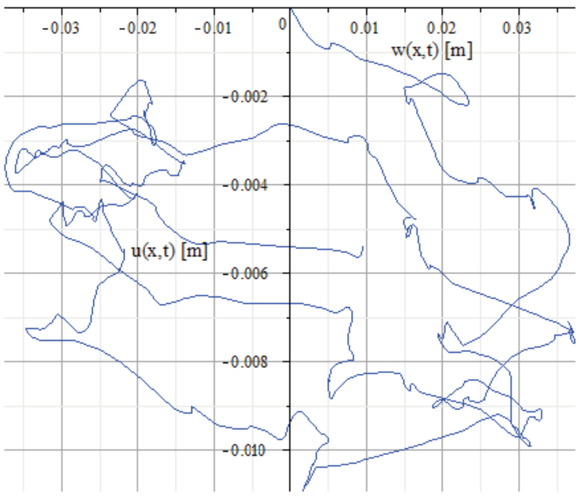

Figure 5. The correlation between the vertical and horizontal displacement of the bucket. Different scale coefficients were used for plotting *u* and *w* values respectively.

This last diagram reveals the stability of the bucket evolution in respect with the entire set of dynamic disturbances initially supposed into the computational model.

On the other side, a spectral analysis applied on bucket displacement signals reveals a set of dominant frequencies and this fact has a very special interest on resonance analysis, because its enlarge the domain of possible resonant motions imminence.

5. CONCLUSIONS

This computational study reveals the non-linear dynamics of a dragline bucket due to transitory regimes that appear during its technological working cycle. The influences of the flexible linkages were considered and the cross-correlated influences of theses about the bucket evolution were dignified.

The results of this research are based on a large set of simplification hypothesis, in order to reduce the area of unknown parameters, to eliminate fuzzy formulation of some dynamic disturbances and to enable only the evaluation of drag cable influences on bucket transitory dynamics.

Hereby, taking into account the entire range of disturbing factors together with a quite realistic simulation of bucket dynamics (in full respect with its structural and functional configuration) will be able to provide very useful information for optimization of bucket driving system and automation.

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