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Original Research Article

The influence of constructive parameters on response of bucket wheel excavator superstructure in the out-of-resonance region

S.M. Bošnjak [a], D.C.D. Oguamanam [b], N.Đ. Zrnić [a,*]

[a] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35, Serbia
[b] Ryerson University, Department of Mechanical & Industrial Engineering, 350 Victoria Street, Toronto, Canada

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ABSTRACT

The influence of constructive parameters on response of bucket wheel excavator superstructure is investigated by using a four degrees-of-freedom discrete dynamic model. Four representative geometric configurations of the superstructure are examined. The maximum displacements and accelerations are observed when the bucket wheel boom is in its lowest position. Further analysis on this configuration is performed to determine the effects of the structural elements stiffness and the bucket wheel weight on the system response. A set of the magnitudes of the parameters that may cause resonance are also determined.

1. Introduction

Bucket wheel excavators (BWEs) belong to the class of earthmoving machines that are exposed to dynamic loads which are primarily attributable to repeated soil–bucket contact, the unbalance of the driving mechanism elements (the BW and the rotational components of the conveyor belt), and the strokes of the fragments of the soil in the course of emptying the buckets. Extremely difficult operating conditions and loads with very pronounced dynamic and stochastic character favors occurrence of failures caused by various types of the 'design-in' defects as well as 'manufacturing-in' defects [6,20]. Structural failures [4,17] in certain cases may lead to catastrophic consequences – machines collapses, as described in [3,18]. Failures of mechanisms [5,11,16,19,24–26] do not bring drastic disruption of structural integrity, but they also cause significant direct costs, as well as indirect costs due to the downtime that substantially diminishes the effects of BWE exploitation [5,6].

Although the current engineering codes and national standards used in calculations ignore the dynamic character of BWE external loads, the investigations of BWE dynamics are extremely important [6]. The aforementioned studies include problems of determining excitation induced by resistance-to-excavation [4,7,10], problems of determination and measurement of natural frequencies of BWEs' structures as well as their vibrations during mining process [8,9,12–15,21–23].

* *Corresponding author*. Tel.: +381 63 287 193; fax: +381 11 3370364; mobile: +381 11 33 02 454.
E-mail addresses: sbosnjak@mas.bg.ac.rs (S.M. Bošnjak), doguaman@ryerson.ca (D.C.D. Oguamanam), nzrnic@mas.bg.ac.rs (N.Đ. Zrnić).

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Fig. 1 – BWE SchRs 1760: total weight (with mobile conveyor) 3150 t, theoretical capacity 6100 m^3/h.

This paper examines influence of constructive parameters on response of BWE SchRs 1760 superstructure (Fig. 1) in the out-of-resonance region. As it was stated in [6], the analysis of the dynamic behavior of BWE is of an extreme importance, above all, in order to prevent the possible occurrence of the resonance in the system and to create a basis for the analysis of the stress conditions in structural elements of the system, as well as for calculation of lifetime.

2. Governing equations of motion

A planar four DOF dynamic model of BWE SchRs 1760 superstructure (Fig. 2) is developed based on the previous investigations [1,2] in a manner described in [6] while the load due to resistance-to-excavation is defined according to the procedure described in [4,7].

Having in mind that in practice free vibration responses are quickly attenuated due to damping, attention is given to the forced vibration response. The application of Lagrange's principle yields a system of governing differential equations which describe the system vibrations in the vertical plane

$$[m]\{\ddot{q}\} + [k]\{q\} = \{Q\}. \tag{1}$$

The vector of generalized non-potential forces is given as

$$\{Q\} = \{Q_0\} + \sum_{n=1}^{\infty}\{Q_n\}\sin(n\Omega t), \tag{2}$$

where Ω is the excitation fundamental circular frequency. It is defined according to the expression

$$\Omega = \frac{\pi n_{BW} n_B}{30} = \frac{\pi \times 4.16 \times 14}{30} = 6.1\ s^{-1} \tag{3}$$

where n_{BW} = 4.16 rev/min is number of speed of the BW and n_B = 14 is the total number of buckets on the BW.

The particular solution to the governing equations in the out-of-resonance region is assumed as

$$\{q_p\} = \{a_p^{(0)}\} + \sum_{n=1}^{\infty}\{a_p^{(n)}\}\sin(n\Omega t). \tag{4}$$

The above expression is introduced into Eq. (1) to the term its coefficients the use of which permits the expression of the system acceleration and displacement as

$$\{\ddot{q}\} = \{\ddot{q}_p\} = -\sum_{n=1}^{\infty}(n\Omega)^2[R(n\Omega)]^{-1}\{Q_n\}\sin(n\Omega t), \tag{5}$$

$$\{q\} = \{q_p\} = [k]^{-1}\{Q_0\} + \sum_{n=1}^{\infty}[R(n\Omega)]^{-1}\{Q_n\}\sin(n\Omega t), \tag{6}$$

where $[R(n\Omega)] = [k] - (n\Omega)^2\,[m]$.

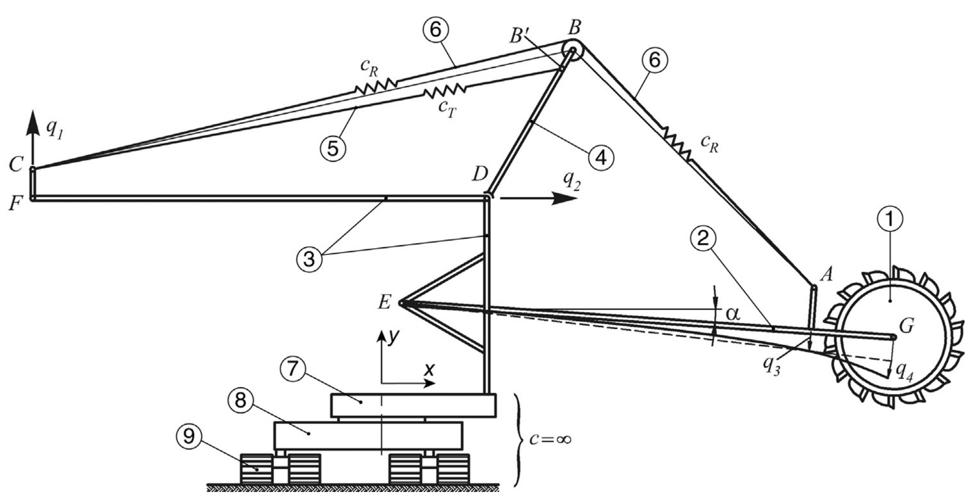

Fig. 2 – Discrete dynamic model in vertical plane: 1 – bucket wheel (BW) with drive; 2 – bucket wheel boom (BWB); 3 – pillar with counterweight arm (PA); 4 – portal; 5 – portal tie-rods (PTR); 6 – rope system for BWB hanging, 7 – slewing platform, 8 – undercarriage, 9 – crawler travel gear, q_1 – the absolute displacement of the counterweight center of gravity; q_2 – the absolute horizontal displacement of the pillar apex; q_3 – the displacement of the point where the ropes of the hanging system are attached to the BWB, perpendicular to the axial axis of the boom; q_4 – the displacement of the center of gravity of the BW with drive unit, perpendicular to axial axis of the BWB; G – center of gravity of BW with drive; α – angle of the BWB inclination.