THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICHAL ENGINEERING, ISSN 1224-5615
2013

ON DYNAMICS OF BUCKET WHEEL EXCAVATORS WITH RADIAL DIGGING

Dr.Eng. Carmen DEBELEAC
"Dunărea de Jos" University of Galati,
Research Center for Mechanics of Machines
and Technological Equipments

ABSTRACT

The paper presents the influence of some structural and operating parameters on external load characteristics caused by resistances to reclaiming at bucket wheel in the radial digging process.

KEYWORDS: excavator, multi-buckets, resistance force, simulation

1. INTRODUCTION

Excavators with radial digging (see Fig.1) belong to the most complex digging machines with continuous action which are widely used in the coal mining industry. From the constructive point of view, these earthmoving machines are composed by a carriage platform, the bucket wheel, slewing, hoisting mechanism, crawler, and electric equipment. The large distances between the different mechanisms of the equipment, require to adopt a kinematic scheme with individual electric engines. Thereby, the driving mechanism of the multi-buckets wheel, composed by electric engine and gear-box, is mounted at the end of the working equipment frame. In the same place is mounted the driving mechanism of the auxiliary feeder conveyor.

Fig. 1. Excavator with radial digging

Modern excavators with radial digging have the following technical performances:

- rotor diameter: 1,6…16,5 m;
- number of discharges per minute: 30…130;
- bucket capacity: 16…2400 l;
- productivity: 400…22700 m^3/h;
- maximal weight: 3000 tone;
- digging height: 5…70 m.

The duty cycle is carried out by combining two motions: rotation of the bucket-wheel in the vertical plane and slewing of the equipment in the horizontal plane.

2. SPECIFIC DIGGING RESISTANCE AT THE BUCKET WHEEL

Generally, the excavation process is affected by:

a) characteristics of soil to be excavated (e.g. physical, mechanical and structural proprieties);
b) constructive parameters of the working equipment (e.g. bucket capacity, shape and condition of tooth and cutting edge);
c) parameters of the working cycle (e.g. productivity, cutting speed, platform rotation speed).

It is very difficult to demonstrate the individual contribution of previous parameters to the dynamic working cycle of bucket wheel excavator.

Based on the references [6, 14] the specific coefficients of force resisting excavation are:

- coefficient k_L which is the length unit of the active part of bucket cutting edge (cutting length), in daN/cm;
- coefficient k_F which represents the chip cross section area unit, in daN/cm^2.

Both coefficients depend on many parameters (Fig.2) such as: bucket volume V_0, chip cross section area A_S, chip cross section thickness, excavator capacity, etc.

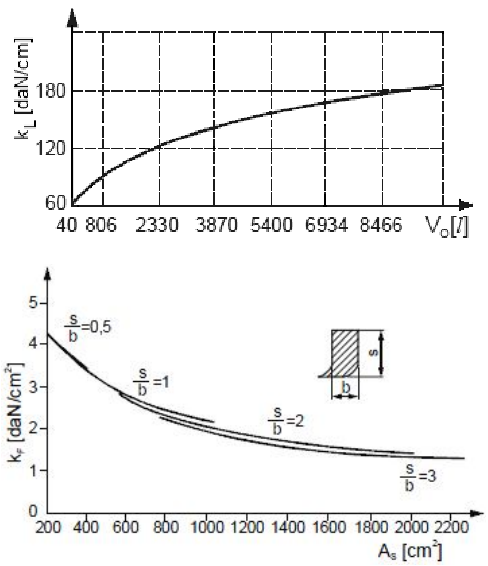

Fig.2. Dependence of the specific digging resistance [2, 3]

Researches in this field [1] have shown that the coefficient k_L can be mathematically described by the nominal law of distribution and its mean values are given in Table 1 [13].

Table 1. Specific digging resistance

Digging environment	Mean value k_L, daN/cm	Standard deviation
Fault zone	43,6	104
Transitional zone	61,0	107
Gray clay	69,2	158

3. DIGGING FORCES AND REQUIRED TORQUE AT THE BUCKET WHEEL

In the radial excavation process, the digging force acting upon the bucket represents a resultant of many forces situated in a spatial configuration, such as: cutting force, friction force and inertial force. The lateral force F_Y and the normal force F_Z (see Fig.3) can be expressed by the tangential force F_X using the following relations:

$$F_Y = \lambda_y F_X , \quad (1)$$

$$F_Z = \lambda_z F_X , \quad (2)$$

where λ_y and λ_z represent the ratio coefficients of the normal and side components of the resistance to digging.

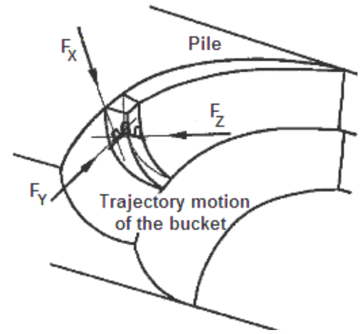

Fig.3. Digging forces at the bucket wheel

The experimental tests demonstrated that the multiplication factor λ_z has different value for each position of the bucket, as it can be seen in Table 2 [12].

Table 2. Values of the coefficient λ_z

Cutting angle, α	λ_z
24^0	0,5…0,8
48^0	1,0…1,1
72^0	1,0…1,1
90^0	0,5…0,8

For a single bucket, the cutting force according to [1] is given by the following equation (see Fig.4):

$$F_X = F_{ti}(\psi) = k_L \cdot l_i \cdot f_i(\psi), \quad (3)$$

where

$$f_i(\psi) = \begin{cases} \sin\psi & \text{if} \quad 0 \le \psi \le \pi/2 \\ (\alpha-\psi)/(\alpha-\pi/2) & \text{if} \quad \pi/2 < \psi \le \alpha \\ 0 & \text{if} \quad \psi > \alpha \end{cases} . \quad (4)$$

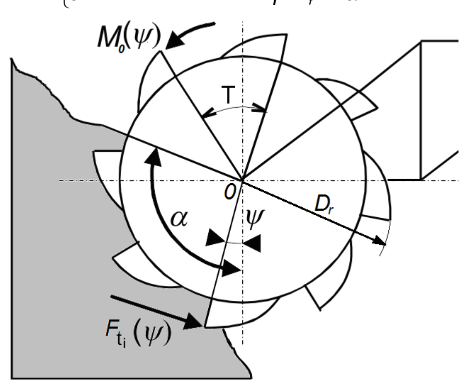

Fig.4. Schematic diagram for cutting force

The notations from Eqns. (3) and (4) have the following significances: Ψ - the angular position of the bucket; α – the total cutting angle; l_i – the cutting contour length of the bucket.

According to [7], the real buckets cutting contours length can be calculated as:

$$L = \sum_{i=0}^{n} l_i f_i(\Psi) + 2x(t) \sum_{i=0}^{n} \cos\left(\Psi + \frac{2i\pi}{z}\right) \quad (5)$$

where n represents the number of buckets that are simultaneously in mesh with the soil; $x(t)$ – the bucket wheel vertical displacement; z - the total number of buckets.

The effect of dynamic behavior of the bucket wheel involves significant deviations from the bucket cutting contours ideal path [7].

The distance between two consecutive buckets is given by the following relation:

$$T = \frac{2\pi}{z}. \quad (6)$$

In Figure 5 is shown the variation of the cutting force acting upon a single bucket and it is observed the dependence of its magnitude in respect with time and implicitly with the angular position of the bucket. At time $t=8$ s, the bucket motion becomes periodic.

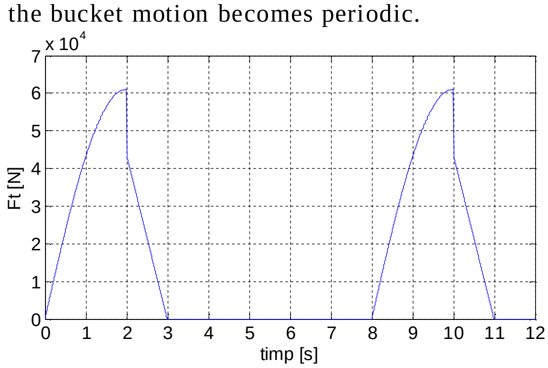

Fig.5.Cutting force simulation for a single bucket

Summing the individual cutting forces a developed at the bucket which is digging (disposed between the 120^0-135^0 on the circumference of the wheel, that means 3 - 4 buckets), it is obtained:

$$F_t = F_t(\Psi) = \sum_{i=1}^{n} F_{ti}(\Psi). \quad (7)$$

The experimental tests established that the application point of resultant cutting force is at $(0,05 - 0,1)D_r$ distance, out of wheel, and the position to the respect with the horizontal line growing through the centre of the wheel corresponded to angle $\alpha_0 = 22^0 \ldots 28^0$ [12].

The resistant torque M on rotor wheel is a function of angular displacement and is given by the following relation:

$$M = M(\psi) = F_t(\Psi)\frac{D_r}{2}. \quad (8)$$

The random behavior of the resistance forces acting on each bucket in the digging process generates a disturbance behavior of the resistance torque on buckets wheel axle.

4. STRUCTURAL DYNAMIC REGIME SIMULATION

A major problem in the modeling of main drive systems behavior from an excavator with radial digging is the estimation of the external excitations as an effect of interaction between soil and buckets.

Nowadays, the estimation of the transmitted loads from the working wheel to the boom structure or to the carriage platform was performed using computer 3D models and several methods for behavior simulation and stress analysis useful for fatigue estimation and diagnosis of the mechanical parts [8, 11, 10,15].

In the digging operation, the bucket wheel are predominantly undergoes vibrations in the vertical plane due to the variable magnitude of the cutting forces developed because of inhomogeneous properties of the pile [5, 7].Also, the oscillatory motions of the working equipment in the horizontal plane have been investigated and been simulated with various methods by several researchers [4, 9].

The dynamic behavior of the boom can be studied based on the simplified model given in Figure 6.

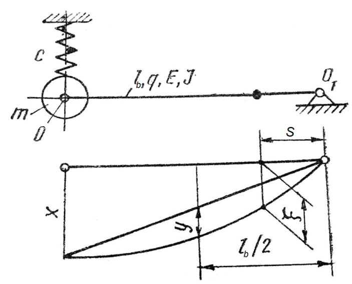

Fig.6. Simplified dynamic model of the boom

If we suppose that the boom deformation in the vertical plane is propagated by the law $y\sin(\pi s / l_b)$, then we can write the expressions of the kinetic and potential energies such as:

$$E_c = \frac{1}{2} m\dot{x}^2 + \frac{q\int_0^{l_b} \dot{\zeta}^2 ds}{2}, \quad (9)$$

$$U = \frac{\int_0^{l_b} \ddot{\zeta}^2 E J_0 ds}{2} + \frac{kx^2}{2}, \quad (10)$$

where

$$\xi = y\sin\frac{\pi s}{l_b} + \frac{x}{l_b}s \quad , \tag{11}$$

and x represents the arrow in the point O; y – the arrow at the boom middle.

Replacing the expressions of two energies in the Lagrange equations by the second order it results:

$$\begin{aligned} &\left(m + \frac{ql_b}{3}\right)\ddot{x} + kx + \frac{ql_b}{\pi}\ddot{y} = 0;\\ &\frac{ql_b}{\pi}\ddot{x} + \frac{ql_b}{2}\ddot{y} + \frac{EJ_0\pi^4}{2l_b^3}y = 0. \end{aligned} \tag{12}$$

Knowledge of the real vertical displacement of the bucket wheel enables to solve the differential equations which describe the oscillation of the lifting subsystems elements, the bucket wheel drive system and the supporting structure of bucket wheel.

In real situations, these vibrations have small amplitude a few centimeters, (Fig.7) and influence the characteristics of the digging force (intensity and frequency) to about 6 ÷ 7%.

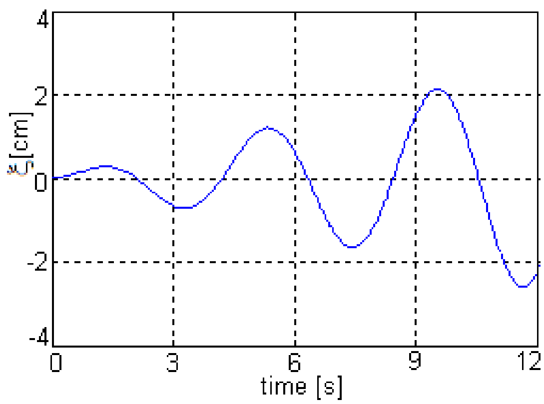

Fig.7. Time evolution of the boom motion

5. CONCLUSIONS

Taking into account the remarks in the previous paragraphs can be formulated the following conclusions: both deterministic and random dynamics of the equipment deeply affect the technological performance level so that there has to be a permanent monitoring process of the global dynamics in order to maintain the quality index in the range of normative requirements.

Supposing the great complexity of this kind of technological equipment, it is obvious that the potential sources of random actions are multiple, but most of them have minor impact influences. Hereby, for a serviceable simulation model, it is necessary to consider only the terms provided by the structural dynamics and by the working body – terrain interactions. In addition, the interaction between the equipment and the material must simulated with respect to main cutting phenomena – Eqn.(3), and in terms of dynamic overloads due to the structural rigidity – the second term in Eqn. (5).

REFERENCES

[1] **Arsić, M., Ljamić, D., Ćirković, B.**, *Experimental Analysis of the Workload of the Excavator's Bucket Wheel Drive*, Proceedings, IRMES'95, pp. 346 – 351, Mechanical Engineering Faculty Nis, Nis 1995.

[2] **Bošnjak, S., Zrnic, N., Oguamanam, D.**, *On the Dynamic Modelling of Bucket-Wheel Excavators*, FME Transactions, No. 34, pp. 221-226, 2006.

[3] **Bošnjak, S., Jovković, M., Petković, Z.**, *Simulation of bucket wheel trenchers load caused by force resisting excavation*, Proceedings of the 15th International Conference on Material Handling and Warehousing, pp. 3153 - 3157, Faculty of Mechanical Engineering, Belgrade, 1998.

[4] **Chundnovskii, V.Y.**, *Horizontal vibrations of the excavating part of a rotary excavator and their suppression*, Journal of Machinery Manufacture and Reliability, No. 3, pp. 224-228, 2007.

[5] **Chundnovskii, V.Y.**, *Vertical oscillations of the working unit of a bucket-wheel excavator in a pit face and their suppression*, Journal of machinery manufacture and reliability, no.3, pp.221-227, 2008.

[6] **Dombrovski, N. G.**, *Multi-bucket excavators: theory, construction, calculation*, Mashinostroenie, 1972.

[7] **Golubović, Z., Lekić, Z., Jović, S.**, *Influence of bucket wheel vertical vibration on bucket-wheel excavator (BWE) digging force,* Tehnički vjesnik 19(4), pp. 807-812, 2012.

[8] **Jovančić, P., Ignjatović, D., Maneski, T.,** *Diagnosis of behaviour for support steel structure at a bucket wheel excavator,* Machine Design, pp.383-388, 2008.

[9] **Luu, K. Q., Soffker, D.**, *Dynamic stability of the bucket-wheel boom during operation of the bucket-wheel excavator,* DINAME 2013 - Proceedings of the XV International Symposium on Dynamic Problems of Mechanics M.A., Brazil, February 17-22, 2013.

[10] **Leopa, A., Năstac, S.**, *Dynamical response analysis on a system with one degree of freedom stresses by the different pulse excitation functions*, The Annals of "Dunarea de Jos" University of Galati, Fascicle XIV Mechanichal Engineering, vol.2, pp.71-74, 2010.

[11] **Marinković, Z., Petrović, G.**, *Processing the lifetime of bucket wheel excavator parts in strip mine technologies*, Facta Universitatis, Series: Mechanical Engineering Vol. 2, No 1, pp. 109 – 124, 2004.

[12] **Mihăilescu, Şt., Bratu, P., Goran, V.**, *Maşini de construcţii, vol. 2*, Ed.Tehnică, Bucureşti,1985.

[13] **Petrović, G., Jevtić, V., Mitrović, M., Marinković, Z.**, *External excitations and disturbances with bucket wheel excavators as non-linear and random functions*, Facta Universitatis, Series: Mechanical Engineering Vol.1, No 10, pp. 1339 – 1346, 2003.

[14] **Rasper, L.**, *Der Sshaufelradbagger als Gewinnungsgerat*, Transactions Technical Publications, 1973.

[15] **Sprečić, D., Mulahalilović, F., Mrkaljević, F.**, *Identification the stress on the working wheel carrier of the loading system the bucket-wheel excavator*, MTTER, Vol. 2, Issue 1, pp. 24-28, 2013.