

To the Optimal Use of Technological Capabilities of the Excavator – Dragline in Construction

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Abstract. The mathematical model of motion of system “boom on a turning platform – bifilar suspended bucket” was created. As a control function, we choose the moment of force relatively non-movable base. The length of suspension of the bucket is assumed to be constant. The bucket of excavator is suspended bifilar. The bucket and the arrow needs to be moved from initial rest final rest position. The results of solution of the problem of rapid movement of bucket of excavator - dragline are presented. The structure of an optimal control law has been calculated by means of maximum Pontryagin' s principle and the method of control parameterization. A simple technique of calculations of optimal bucket trajectories has been developed. The dynamic of optimal control laws of the bucket and the arrow has been studied. Special software is created.

1 Introduction

At present technological capabilities of the heavy walking excavator - dragline, for a variety of reasons, are used not fully [1-3]. Relevance of a problem of performance improvement of the excavator – dragline doesn't raise doubts.

In [4-8] developed mathematical optimal control theory. In [9] described an effective method for analysis of maneuvering capabilities of controlled mechanical systems and results of its application for solving the problem of optimum maneuvering of aircraft and spacecraft. In [10] described a numerical method for optimization of high dimensionality systems. These methods based on [4-8].

In [1], using methods of [9-10], provides the results of application of the developed technology to the problem of maximum turn angle dragline - excavator boom within a fixed time interval, with finite damping of occurring oscillations of a bucket, which bifilar attached to a boom of excavator.

This article provides the results of application of the method [9-10] to solve the problem about the fastest movements of a dragline excavator bucket and arrow to a given point with

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finite damping of occurring oscillations of a bucket attached to a boom. The considered problem is reciprocal for the problem of maximum boom swing within a fixed time interval. The results obtained in the article are in complete agreement with the results of solving the problem turn the excavator to the maximum angle within the required time [1].

2 Problem definition

Movement of the model “boom on a turning platform – bifilar suspended bucket” (Fig.1) under certain circumstances may be described by the following system of differential equations [2-3]:

$$\frac{d^2\sigma}{dt^2} + \frac{g}{l}\sigma = \frac{d^2\varphi}{dt^2}, \quad J \cdot \frac{d^2\varphi}{dt^2} = M, \quad (1)$$

where:

- φ - a angle of turning of platform around vertical axis,
- σ - bucket deflection from the boom plane, normalized to the turntable swing axis,
- J - normalized moment of system inertia in relation to the turntable swing axis,
- M - moment of force around the axis of the turntable,
- l - normalized length of the suspension,
- g - gravitational acceleration,
- t - time of motion.

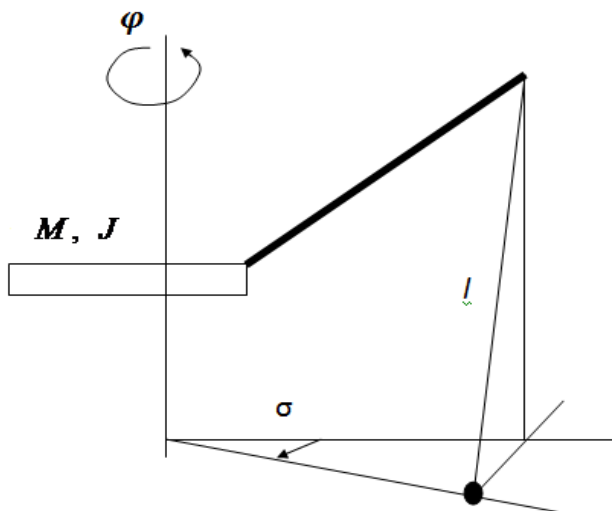


Fig.1. Scheme of the boom on a turning platform.

The system of equations (1) is true under the assumption that the mass of the bucket is negligible compared to the total weight of the boom and driving the platform. The bucket may

not be oscillating in the plane of the boom. The angle characterizing the deviation of the bucket from the plane of the arrows is small enough.

As a control function, we choose $M(t)$ the moment of force relatively non-movable base. The length of suspension of the bucket is assumed be constant.

Let in the initial moment of time $t = 0$ the system was at rest:

$$\sigma(0) = 0, \quad \varphi(0) = 0, \quad \dot{\sigma}(0) = 0, \quad \dot{\varphi}(0) = 0. \quad (2)$$

The control function $M(t)$ should be restricted by the value M_{13} :

$$|M(t)| \leq M_{13}, \quad 0 \leq t \leq T.$$

(3)

Its required to minimize the total time of motion:

$$T \rightarrow \min, \quad (4)$$

from the rest state (2) to the desired rest state:

$$\sigma(T) = 0, \quad \dot{\sigma}(T) = 0, \quad \varphi(T) = \varphi_{13}, \quad \dot{\varphi}(T) = 0. \quad (5)$$

Control function $M(t)$ should provide that the maximum angular speed of turn of an arrow shan't exceed the given value C_1 :

$$\max_t \left| \dot{\varphi}(t) \right| \leq C_1. \quad (6)$$

The formulated problem of optimum control may be reduced to the standard problem of optimum control with limitations for the control function and phase variable [5,10].

Note that the formulated problem is similar to the problem of minimum time of movement of a mathematical pendulum with a movable suspension point from one equilibrium position to another equilibrium position [8].

3. Algorithms of the method of controls parameterization

Qualitative analysis of the optimum control structure is provided in [1-2]. Optimal controls laws were founded. These functions takes the form as shown at the Fig. 2. In order to get these functions were founded the algorithms of the method of controls parametrization. The provided below algorithms use the essential properties of the symmetry of control function.

The control laws shown at the Fig. 2a will be parametrized as $\xi = t_2$. Let's take $z = \sigma(T)$ as the offset. The corresponding boundary value problem of the maximum principle then reduces to a single non-linear equation $z(\xi) = 0$. This equation was solved using Newton method [5]. The relation $z = z(\xi)$ is calculated basing on the numeric integration (1) with initial conditions (2). Moments of time t_1, t_3, t_4, t_5 will be uniquely determined by the limitations of the movement time T , angular turntable swing

velocity and symmetry condition of the required controlling function. Limitations $\dot{\varphi}(T) = 0$ and $\dot{\sigma}(T) = 0$ will be observed automatically due to symmetry.

The control laws shown at the Fig. 2b will be parametrized as $\xi = (t_1, t_2)$. Let's select $z_1 = \sigma(T)$, $z_2 = \dot{\sigma}(T)$ as offset vector $z = (z_1, z_2)$ components. The corresponding boundary value problem of the maximum principle then reduces to a system of second order non-linear equations $z(\xi) = 0$. This equation was solved using Newton method [5]. Moments of time t_3, t_4, t_5, t_6 will be uniquely determined by the limitations of the movement time T , angular turntable swing velocity and symmetry condition of the required controlling function. The limitation $\dot{\varphi}(T) = 0$ will be observed automatically due to symmetry of the controlling function.

The control laws shown at the Fig. 2c will be parametrized by 2 parameters $\xi = (t_2, t_3)$. Let's select $z_1 = \sigma(T)$, $z_2 = \dot{\sigma}(T)$ as offset vector $z = (z_1, z_2)$ components. The corresponding boundary value problem of the maximum principle then reduces to a system of second order non-linear equations $z(\xi) = 0$. This equation was solved using Newton method [5]. Moments of time t_1, t_4, t_5, t_6, t_7 are uniquely determined as described above, condition $\dot{\varphi}(T) = 0$ will be observed automatically.

The control laws shown at the Fig. 2d is limiting law to the laws shown at the Fig. 2a, 2b, 2c.

Calculations show that control laws created by means of method of controls parametrization and corresponding trajectories meet the required extremum conditions specified as Pontryagin's maximum principle.

Note that the described algorithms actually are simple methods of calculation of optimum trajectories and controls functions, since they allow to create optimum regimes basing on solution of algebraic equations of the second order by algebraic numerical methods.

Qualitative analysis of the necessary extremum conditions for the problem (1)-(6) demonstrated that they are equal to the respective extremum conditions for the problem of maximum turn boom swing within a fixed time interval [2]. Therefore, optimal control laws and trajectories for the problems (1)-(6) will be also optimal for the problem described in [1], and vice versa.

4 Results of calculations

Calculations were carried out in case of the following parameter values:

$$v^2 = \frac{g}{l} = 0,6 \frac{1}{c^2}, \quad c_1 = 0,12 \frac{pad}{c}, \quad M_{13} = J \cdot 0,02 \text{ H} \cdot \text{M}.$$

The main results of solution of the problem of rapid movement of bucket of excavator - dragline are presented in Table 1.

Table 1. Key parameters of optimal motion of bucket and boom.

The time of motion, sec.	16	16,472	18	20
The angle of rotation, deg	67,1	72	74,8	81,2
The form of the optimal control	Fig.2a	Fig.2b	Fig.2c	Fig.2d

5 Conclusion

The main results of the investigation can be summarized as follow:

1. The method of investigation of maneuvering capabilities of controllable mechanical systems was adapted for the problem of increasing performance of excavator - dragline.
2. Efficiency of the developed method was demonstrated through solving the problem of operating speed during swing of boom of dragline excavator to the required angle with finite damping of occurring oscillations of a bucket bifilarly attached to a boom. Obtained results are in complete agreement with the results of solving the problem turn the excavator to the maximum angle within the required time [1].
3. The developed model is the base of special purpose software. The described model is included into the automated management system of enterprise. The model is used for calculation of optimal booms trajectories of dragline - excavator. To solve the optimal control problem at computer it takes less 2 second.
4. The described algorithms of the method of parametrization of control laws actually can be used in practice as simple methods of calculation of optimum trajectories and controls functions

References

1. R.Z. Khayrullin, On the research of maneuverability of excavator - dragline, Vestnik MGSU, **4**, 49-53, (2010)
2. L.D. Pevzner, R.Z. Khayrullin, *XXVIII - International Symposium "Computer applications in the minerals industries"*. October 20-22, 1999, Colorado School of Mines. Golden, Colorado, USA, 863-870, (1999).
3. R. Z. Khayrullin, Automated dynamic load control by Electromechanical systems of excavator - dragline, Vestnik MGSU, **7**, 125-129 (2012)
4. L.S. Pontryagin, V.G. Boltyansky, R.V. Gamkrelidze, E.F. Mishchenko. *Mathematical theory of optimal processes*, (1961)
5. R. P. Fedorenko, *Approximate solution of optimal control problems*, (1978)
6. A. Bryson, Y. Ho, *Applied Optimal Control*. Blaisdell Publishing, Waltham, MA, (1969)
7. R. Vinter. *Optimal Control*. Birkhauser, Boston, (2000)
8. L.D. Akulenko. *Asymptotic methods of optimal control*, (1987)
9. Yu. F. Golubev, R.Z. Khayrullin, On the research of maneuverability of spacecraft during the atmosphere descent, Theory and control systems journal, **4**, 146-151, (1996)
10. R.Z. Khayrullin, Optimization of high dimensionality systems with the use of ILOG software components, Vestnik MGSU, **8**, 157-163, (2013)