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KINEMATICS AND DYNAMICS OF WORKING MECHANISM OF HYDRAULIC EXCAVATOR

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ABSTRACT
In this paper are studied kinematic and dynamic parameters of working mechanism of hydraulic excavator. The manipulator is designed by the SolidWorks, than with Dynamic Designer are simulated velocities and forces. As a result are derived the relationships for force in hydraulic cylinder, reaction force in joint betweenarm and jib.

INTRODUCTION

The study of kinematic and dynamic parameters of manipulator of hydraulic excavator is based. The mechanism of this manipulator is plane multilinkage, that consists of arms joined and hydraulic cylinders.

The aim of this paper is to create methodology for kinematic and dynamic parameters research of working mechanism of hydraulic excavator.

We consider the working mechanism as conjunction of jib, arm and bucket, that are joined by the cylindrical joints and hydraulic cylinders. The working process is based on rotation of arm to jib with hydraulic cylinder.

A model of arm and jib is shown in Fig.1.

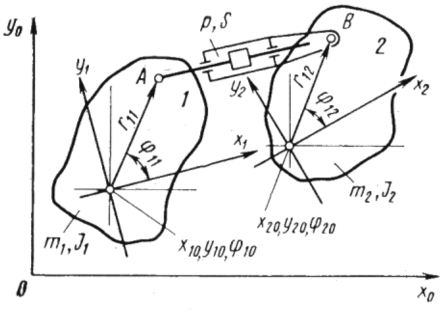

Figure 1. A model of mechanism arm – jib

The body 1 presents the jib, the body 2 – arm. They are joined in point A and point B with hydraulic cylinder. The pressure and area of the cylinder are known.

Simulation of such a mechanism is made by using Lagrange equation of the first type with unknown multipliers.

$$\left.\begin{aligned} m_i\ddot{x}_{i0} + \sum_{s=1}^{p}\lambda_s\frac{\partial\Phi_s}{\partial x_{i0}} &= Q_{xi};\\ m_i\ddot{y}_{i0} + \sum_{s=1}^{p}\lambda_s\frac{\partial\Phi_s}{\partial y_{i0}} &= Q_{yi};\\ J_i\ddot{\varphi}_{i0} + \sum_{s=1}^{p}\lambda_s\frac{\partial\Phi_s}{\partial \varphi_{i0}} &= Q_{\varphi i};\end{aligned}\right| \tag{1}$$

Where Qx_1, Qy_1 are components of resultant force in Dekart's system for the i-body; $Q_{\varphi i}$ – correspondingly moment; λ_s – unknown multipliers; F_s – joint function. Let's take symmetrical cylinder. This system is forced by the unconservative force F=pS. The pressure p is taken as known. To estimate the forces Q_i for equations (1) we consider elementary work

$$dA = Q_i dq_i \tag{2}$$

The cylinder length l is:

$$l = \sqrt{\begin{aligned}&\{(x_{20}-x_{10})+[r_{21}\cos(\varphi_{20}+\varphi_{21})-r_{11}\cos(\varphi_{10}+\varphi_{11})]\}^2+\\ &+\{(y_{20}-y_{10})+[r_{21}\sin(\varphi_{20}+\varphi_{21})-r_{11}\sin(\varphi_{10}+\varphi_{11})]\}^2\end{aligned}} \tag{3}$$

Then:

$$dA = pSdl = pS\left(\frac{\partial l}{\partial x_{10}}dx_{10} + \frac{\partial l}{\partial y_{10}}dy_{10} + \frac{\partial l}{\partial \varphi_{10}}d\varphi_{10} + \frac{\partial l}{\partial x_{20}}dx_{20} + \frac{\partial l}{\partial y_{20}}dy_{20} + \frac{\partial l}{\partial \varphi_{20}}d\varphi_{20}\right)$$

Let's assign L to equation (3), then the derivatives $\partial l / \partial q_i$ are $\frac{\partial l}{\partial q_i} = \frac{1}{2\sqrt{L}}\frac{\partial L}{\partial q_i}$, and the forces (2) are:

$$F_1^x = pS\frac{1}{2\sqrt{L}}(-a); \quad F_1^y = pS\frac{1}{2\sqrt{L}}(-b);$$
$$M_1 = pS\frac{1}{2\sqrt{L}}L; \quad F_2^x = -F_1^x; \qquad (4)$$
$$F_2^y = -F_1^y; \quad M_2 = pS\frac{1}{2\sqrt{L}}M \cdot$$

For the moments M1 and M2 we have:

$$M_1 = r_{11}[F_1^x \sin(\varphi_{10}+\varphi_{11}) - F_1^y \cos(\varphi_{10}+\varphi_{11})];$$
$$M_1 = r_{21}[-F_2^x \sin(\varphi_{20}+\varphi_{21}) + F_2^y \cos(\varphi_{20}+\varphi_{21})]$$

Recognizing the friction force in the hydraulic cylinder, the force $F_{1,2}$ is

$$F'_{1,2} = F_{1,2} + \mu F_{1,2} sign\dot{i} \qquad (5)$$

The diferential equation system is

$$\begin{bmatrix} m_1 & & & & & \\ & m_1 & & & & \\ & & J_1 & & & \\ & & & m_2 & & \\ & & & & m_2 & \\ & & & & & J_2 \end{bmatrix}^{I} \cdot \begin{Bmatrix} \ddot{x}_{10} \\ \ddot{y}_{10} \\ \ddot{\varphi}_{10} \\ \ddot{x}_{20} \\ \ddot{y}_{20} \\ \ddot{\varphi}_{20} \end{Bmatrix} = \begin{Bmatrix} F_{10}^x - F_1^x(1+\mu\, sign\,\dot{i}) \\ F_{10}^y - F_1^y(1+\mu\, sign\,\dot{i}) \\ M_{10} + r_{11}[F_1^x(1+\mu\, sign\,\dot{i}) \times \\ \times \sin(\varphi_{10}+\varphi_{11}) - F_1^y(1+\mu\, sign\,\dot{i}) \times \\ \times \cos(\varphi_{10}+\varphi_{11})] \\ F_{20}^x + F_2^x(1+\mu\, sign\,\dot{i}) \\ F_{20}^y + F_2^y(1+\mu\, sign\,\dot{i}) \\ M_{20} + r_{21}[-F_2^x(1+\mu\, sign\,\dot{i}) \times \\ \times \sin(\varphi_{20}+\varphi_{21}) + F_2^y(1+ \\ +\mu\, sign\,\dot{i})\cos(\varphi_{20}+\varphi_{21})] \end{Bmatrix}^{V}$$

(6)

There is relation for cylinder area S when we calculate the forces $F_{1,2}^x$ and $F_{1,2}^y$

$$S = \frac{S_1}{2}(1+sign\dot{i}) + \frac{S_2}{2}(1-sign\dot{i}) \cdot \qquad (7)$$

Where S1 – piston area; S2 – area behind the piston.

The methods for research the kinematic and dynamic parameters of working mechanism of hydraulic excavator consist of:

1) Create the 3-D Solidworks model
2) Use the Dynamic Designer program

An example for implementation of this methods is:

EXPERIMENTAL WORK

1) We have created the 3-D SolidWorks model of working mechanism of hydraulic excavator Caterpillar with 1m3 bucket volume. This model is shown in Fig.2.

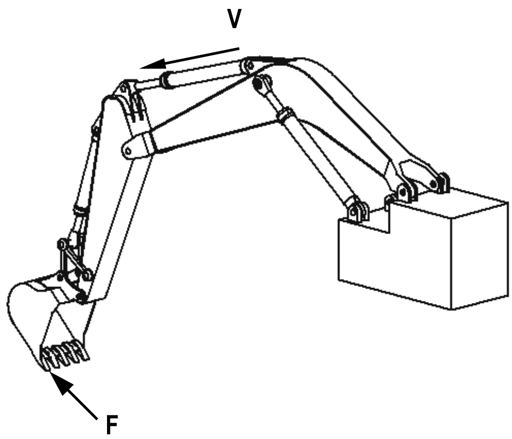

Figure 2. 3-D SolidWorks model

2) The Dynamic Designer program is started and the 3-D SolidWorks model is attached here.
3) We check the joints that were created as SolidWorks model – here we have concentric joint in the hinge between the arm and the jib, the concentric joints in the hinges of hydraulic cylinder and the arm and the jib. There is also a translation joint between the cylinder body and the piston.
4) In this study we assign the translation velocity of the piston to be constant and equal to 0,3 m/s.
5) On the tooth of the bucket we put the constant resistant force F_{bucket} = 20000 N. This is the force of scission of the ground.
In the Fig.3 and Fig.4 are shown the Dynamic Designer work tree and property window respectively.

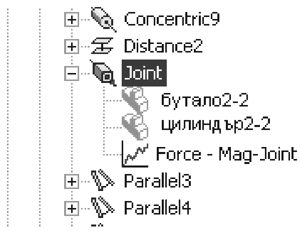

Figure 3. Dynamic Designer work tree

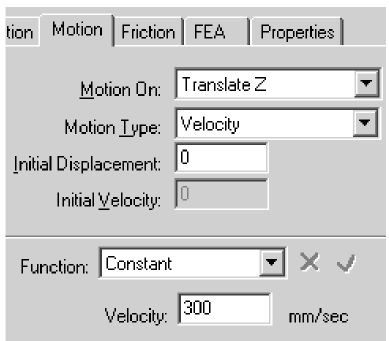

Figure 4. Dynamic Designer property window

6) The created dynamic model is simulated in the Dynamic Designer environment.

RESULTS OF THE EXPERIMENT

The simulation results are shown in Fig.5., Fig.6. and Fig.7., where:

- Fig.5. represents the velocity of the mass center of the bucket;
- Fig.6. represents the piston force;
- Fig.7. represents the reaction force in the hinge between the arm and the jib.

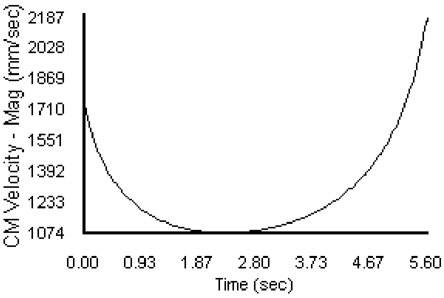

Figure 5. Velocity of the mass center of the bucket

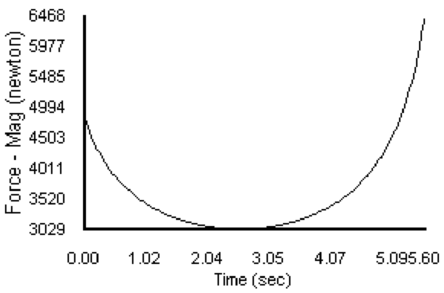

Figure 6. Piston force

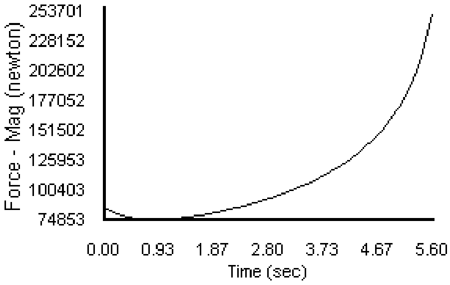

Figure 7. Reaction force in the hinge between the arm and the jib

CONCLUSION

1. A method for study of the kinematic and dynamic parameters of working mechanism of the hydraulic excavator is created. This method includes jointly using the 3-D SolidWorks model and Dynamic Designer.
2. The study of the velocity of the mass center of the bucket, the force of the piston of the hydraulic cylinder and the reaction force in the hinge between the arm and the jib is carried out.
3. The results can be used for creation of a control system of the working process of the hydraulic excavator.

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