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DEVELOPMENT OF MATHEMATICAL MODELS AND ALGORITHMS FOR OPTIMAL CONTROL TO DETERMINE THE PARAMETERS OF THE HYDRAULIC CYLINDER OF A UNIVERSAL ROW-CROP TRACTOR WITH A VARIABLE BASE

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Abstract: The article deals with the application of mathematical modeling of movement and the optimal control algorithm to determine the optimal parameters of the hydraulic cylinder of a universal row-crop tractor with a variable base. Mathematical models have also been developed based on Lagrange's equations of the second kind and an algorithm for optimal control of the processes of hydraulic cylinder functioning using the Pontryagin maximum principle. Numerical Runge-Kutta method is applied to study the optimal parameters of the hydraulic cylinder. A computational experiment was carried out and the optimal parameters of the movement and design of the hydraulic cylinder were determined. On the basis of the obtained functioning parameters and Hamelton's equations, the energy states of the hydraulic cylinder of a universal row-crop tractor with a variable base are determined.

Key words: hydraulic cylinder, universal row-crop tractor with variable base, mathematical model, dynamic model, optimal control algorithm, energy state.

Introduction

In universal row-crop tractors, hydraulic systems for various purposes are most widely used-starting with a steering drive (power steering), and ending with hydrostatic drives of excavators, hoists and other equipment. All these systems are built on the same principles and a common component base, and in them the hydraulic power cylinders are the key parts.

Hydraulic cylinder - hydraulic power element which converts hydrostatic pressure of the working fluid into mechanical work. The cylinder is one of the simplest types of hydraulic motor that converts fluid pressure into reciprocating movement of the working body. At the same time, hydraulic cylinders have a high efficiency and are capable of developing forces of tens of tons, which ensured their widest distribution.

Materials and methods

Modeling and controlling the parameters of the hydraulic cylinder allows you to optimize the parameters using an appropriate mathematical model, and also increases the reliability of the normal functioning of the system [1]. Therefore, one of the priority tasks is the developing a mathematical description of the motion of a hydraulic cylinder operating in dynamic modes. The effectiveness of solving such problems largely depends on the goal setting and the choice of modeling methods.

Our goal is to select the parameters of the hydraulic cylinder for optimal control of the change in the base of the universal row-crop tractor.

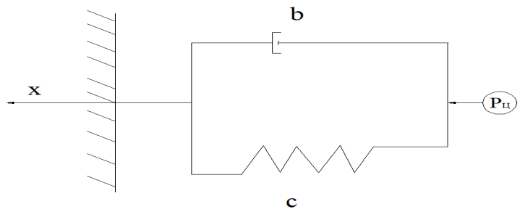

Fig. 1. Dynamic model of the hydraulic cylinder

We will make a mathematical model of the motion of the movement of the changing base of universal row-crop tractors using the Lagrange equation of the second kind [2]:

$$\left.\begin{aligned} m_{ш}\ddot{x}_{ш} &= P_{гц} - b_{ш1}(\dot{x}_2 - \dot{x}_4) + c_{ш1}(x_1 - x_3), \\ m_{к}\ddot{y}_{к} &= b_{ш1}(\dot{x}_2 - \dot{x}_4) + c_{ш1}(x_1 - x_3) - P_{ц}, \end{aligned}\right\} , \quad (1)$$

where: $m_{ш}, m_{к}$ - moments of inertia of the hydraulic cylinder, $N \cdot m \cdot s^2$;

$x_{о}, x_{р}$ - linear displacement of the hydraulic cylinder, m;

$y_{д}, y_{р}$ - linear speed of the hydraulic cylinder, m / s;

b - coefficient of viscous resistance of the hydraulic cylinder;

c - coefficient of rigidity of the hydraulic cylinder ;

P_d, P_s – driving force and resistance force, *N*.

Result and Discussions

Calculation of stiffness and viscous resistance of hydraulic cylinder elements:

$$c_1 = \frac{P_{с}}{x_{м}}, \qquad b_1 = \frac{0.64 \cdot c_1}{2\pi v}, \qquad (2)$$

where: $x_{м}$ - linear movement of the hydraulic cylinder rod;

v - process speed m/s;

To determine auxiliary functions by a numerical method, a conjugate system with a variation of the design parameters b_i, c_i was investigated. The results of solving the system using numerical Runge-Kutta methods based on computational experiments using a software package are obtained.

Input parameters

Coefficient of viscous resistance (b, $N \cdot m \cdot s/rad$): 422016

Stiffness (S, $N \cdot m/rad$): 648.8;

Moment ofinertia of the moving part of the object ($J_1, N \cdot m \cdot s^2$): 140

Object's moment of inertia ($J_2, N \cdot m \cdot s^2$): 10

Calculation parameters

Calculation time (t kon): 1.00

Step h calcul: 0.00001.

H print value: 0.1

x0	f(1)	f(2)	f(3)	f(4)	f(5)	f(6)	f(7)	f(8)	Hd	Hp
0	0	1	0	-1	0	-0,422	0	-0,4214	-1	-1
0,1	0,0866	0,8619	0,0863	0,9035	-0,0422	-0,422	-0,0421	-0,4214	-1	-1
0,2	0,1729	0,8626	0,1729	0,8632	-0,0844	-0,422	-0,0843	-0,4214	-1	-1
0,3	0,2591	0,8607	0,2591	0,8606	-0,1266	-0,422	-0,1264	-0,4214	-1	-1
0,4	0,3451	0,8587	0,3451	0,8587	-0,1688	-0,422	-0,1685	-0,4214	-1	-1
0,5	0,4308	0,8567	0,4308	0,8567	-0,211	-0,422	-0,2107	-0,4214	-1	-1
0,6	0,5164	0,8547	0,5164	0,8547	-0,2532	-0,422	-0,2528	-0,4214	-1	-1
0,7	0,6018	0,8528	0,6018	0,8528	-0,2954	-0,422	-0,295	-0,4214	-1	-1
0,8	0,687	0,8508	0,687	0,8508	-0,3376	-0,422	-0,3371	-0,4214	-1	-1
0,9	0,7719	0,8489	0,7719	0,8489	-0,3798	-0,422	-0,3792	-0,4214	-1	-1
1	0,8567	0,847	0,8567	0,847	-0,422	-0,422	-0,4214	-0,4214	-1	-1

Tab. 1. Output parameters of the transient process in the hydraulic cylinder for the changing base of the universal row-crop tractor

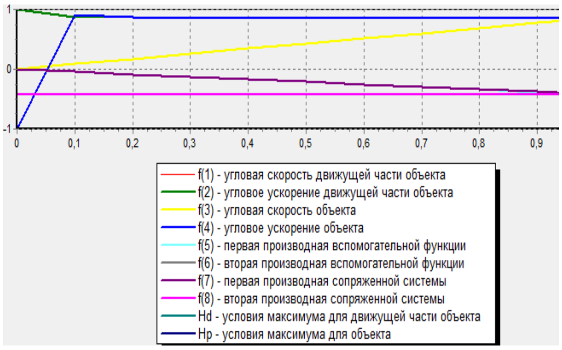

Fig. 2. The graph of the results of the calculation of auxiliary functions and transient processes

After determining the parameters m, b, c, we proceed to the numerical solution of the mathematical model.

Input parameters

Driving moment ($M_1, N\cdot m$): 88

Moment of inertia of the moving part of the object ($J_1, N\cdot m\cdot s^2$): 140

Moment of inertia of the object ($J_{21}, N\cdot m\cdot s^2$): 10

Moment of resistance (Mcc, n * m): 42

Stiffness (s_1, m / rad): 422106

Coefficient of viscous resistance (b_1, $N\cdot m\cdot s/rad$): 648.8

Gear ratio: 1

Process frequency (w, 1 / sec): 0.3

Calculation parameters

Calculation time (t con): 1.00

Step h calcul: 0.00001

H print value: 0.1

x0	f(1)	f(2)	f(3)	f(4)	m_d	m_p	m_{cc}	M_0	p_d	p_p
0	0	0,6286	0	-4,2	88	-42	42	0,0001	0	0
0,1	0,0307	0,2999	0,0301	0,4008	41,9923	4,0077	42	0,0001	0,0013	0,0001
0,2	0,0613	0,3066	0,0614	0,3079	42,921	3,079	42	0,0001	0,0026	0,0002
0,3	0,092	0,3067	0,092	0,3065	42,9346	3,0654	42	0,0001	0,0039	0,0003
0,4	0,1227	0,3067	0,1227	0,3067	42,9333	3,0667	42	0,0001	0,0053	0,0004
0,5	0,1533	0,3067	0,1533	0,3067	42,9333	3,0667	42	0,0001	0,0066	0,0005
0,6	0,184	0,3067	0,184	0,3067	42,9333	3,0667	42	0,0001	0,0079	0,0006
0,7	0,2147	0,3067	0,2147	0,3067	42,9333	3,0667	42	0,0001	0,0092	0,0007
0,8	0,2453	0,3067	0,2453	0,3067	42,9333	3,0667	42	0,0001	0,0105	0,0008
0,9	0,276	0,3067	0,276	0,3067	42,9333	3,0667	42	0,0001	0,0118	0,0008
1	0,3067	0,3067	0,3067	0,3067	42,9333	3,0667	42	0,0001	0,0132	0,0009

Tab. 2. Output parameters of the changing base of the universal row-crop tractor

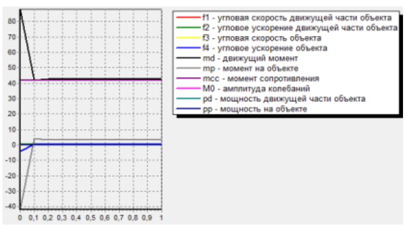

Fig. 3. Graph of the results of calculating the control parameters of the hydraulic cylinder

To find the energy states and calculate the power of the hydraulic cylinder, we use the Hamilton function:

$$\frac{dH}{dt} = \sum_{i=1}^{n}\left(-\frac{\partial H}{\partial x_i} + Q_i\right)\dot{x}_i = \sum_{i=1}^{n} Q_i \dot{x}_i \, . \quad (3)$$

Substituting values of angular velocities $\dot{x}_i$ and the moments of driving forces and resistances $Q_i = M_i$ in determine the energy state of the hydraulic cylinder. The values and graphical dependences of the energy state of UTTWVB are obtained (Fig.4).

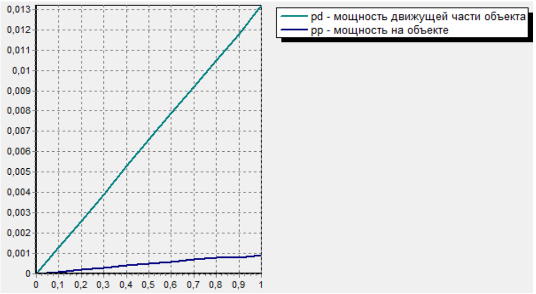

Fig.4. Graph of the results of calculating the energy state of the hydraulic cylinder

Conclusions

On the basis of optimal speed control, the optimal values of the reduced mass, stiffness coefficient and viscous resistance of the hydraulic cylinder are determined by changing the base of a universal row-crop tractor at given values of resistance forces. The obtained values of the optimal parameters of functioning and design made it possible to establish the energy states of the hydraulic cylinder.

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