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RESEARCH OF THE TWO-SECTION AUTOHYDRAULIC HOIST'S BOOM POSITION

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Within the framework of the issue of a hydraladder control system design, which provides the working equipment movement along the most efficient trajectory under accelerations limitation the analytical solution of the problem of the nodal points' position determination of a two-link hydraladder has been obtained. The adequacy of the results has been confirmed experimentally.

Ключевые слова: *autohydraulic hoist, two-section mechanism, service area, analytic solution*

Introduction

For carrying out different works at height (electrical assembly and assembly work, service and repair of facades, traffic lights, road signs, carrying out rescue operations, forest parks maintenance, installation of advertising banners etc.) special autohydraulic hoist (AHH), that can be considered as a kind of special-purpose machinery, is used [1].

The main advantages of AHH are mobility, ease of management, versatility.

In the same time AHH belongs to high-risk equipment, because the life of working people being inside cradle depends on its trajectory and smoothness of movement.

Problem statement

Changeable character of AHH operation mode, due to frequent switching of executive hydraulic cylinders, causes the appearance of dynamic loads, arising as a result of high amplitudes of pressure fluctuations in the hydraulic drive and accelerations of drive mechanisms. And quite often these fluctuations leads to pulling out the turntable of the support frame, bending the upper section of the boom or falling through the bottom fastening of hydrocylinder rise of bottom boom section [2]. Thus there is a problem of ensuring moving AHH boom on the most efficient path while limiting acceleration. Solution of this problem is possible only by implementing the automatic control system (ACS).

In the first stage of designing this ACS it must be obtained depending, binding values and the position of the AHH mechanism. These data are required to provide moving working equipment on the most efficient trajectory while limiting acceleration. It is advisable to have an analytical solution task of determining location of nodal points of autohydraulic hoist mechanism.

Publication analysis

As the analysis of literature shown, not enough attention paid to solution tasks of effective and safe exploitation of AHH by ensuring smoothness of moving boom's section. In [3] ACS of AHH movement has been considered, desired laws of generalized coordinates and their speeds in moving sections of AHH from one position to another have been determined, management of AHH boom movement is carrying out by PD-regulator.

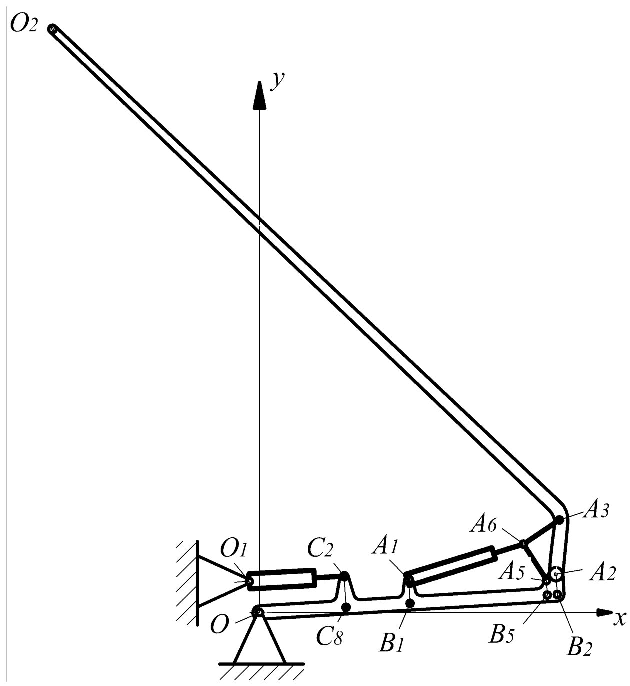
In the same time similar problems for different types have been discussed quite extensively. In particular, professor Loveykin and his students' studies [4, 5, 6] are devoted to the reduction of dynamic loads on working equipment of loader cranes.

In the monograph [7] construction manipulator, including AHH as complex dynamic system that consists of mechanic subsystem, subsystem of hydraulic drive and control subsystem has been analyzed, the algorithms for system of automated simulation of the optimal trajectory of the working body of the construction manipulator have been considered. However, the emphasis has on automation machine design, but problems of working process management haven't been considered. In work [8] the system of reducing dynamic loads and damping fluctuations, when the boom of forest manipulator is driving, has been developed.

Thus, the analysis of publications allows to argue that research aimed at reducing the execution time of working operations of AHH in reducing dynamic loads by limiting the acceleration are relevance. To do this, at first the possible positions of the AHH boom must be defined. The solution of noticed problem is the purpose of this article.

Building service area of AHH

As an example, two-section AHH with rotary units located at the educational-scientific production base (ESPB) of HNAHU was considered (picture 1).



Picture 1 – Scheme of experimental AHH

According to the results of measurements the coordinates of merging hydrocylinders' points (points C_2 and A_1) and the coordinates of A_2, A_5 and A_3 points in coordinate system, bounding with bottom boom section, have been identified. The distances between points A_2, A_3 and O_2 on the upper boom section have been measured too.

Based on obtained data, calculating the position of the mechanism for the five lengths values of hydrocylinder O_1C_2 management of bottom section (from 770 to 910 mm with step 35 mm) and five length values of hydrocylinder A_1A_6 management of upper boom section (from 1020 to 1400 mm with step 95 mm) has been made.

As an initial data the following constant values have been taken:

- coordinates of hinges, located in bottom section of hoist in related coordinate systems to this section;
- horizontal and vertical coordinate of hinge of hydrocylinder fastening of lifting the knee to the machine frame;
- distances C_2C_8 and OC_8, A_1B_1 and OB_1, A_5B_5 OB_5, A_2B_2 and OB_2.

It's also supposed that using outriggers, hoist frame was set in a horizontal position. Coordinates of point C_2 have been determined from the triangle OC_1C_2 (picture 1):

$$OO_1 = \sqrt{xO_1^{\,2} + yO_1^{\,2}}\ ; \tag{1}$$

$$OC_2 = \sqrt{OC_8^{\,2} + C_2C_8^{\,2}}\ ; \tag{2}$$

$$O_1OC_2 = \arccos\left(\frac{OO_1^{\,2} + OC_2^{\,2} - O_1C_2^{\,2}}{2 \cdot OO_1 \cdot OC_2}\right). \tag{3}$$

Using the coordinates of O and O_1 points, the angle of inclination side $OO_1$to the horizon

$$O_1Ox = \mathrm{arctg}\left(\frac{xO_1}{yO_1}\right). \tag{4}$$

The angle C_2OC_8 for all positions of the mechanism was kept constant

$$C_2OC_8 = \mathrm{arctg}\left(\frac{C_2C_8}{OC_8}\right). \tag{5}$$

It allows to determine the angle α of inclination bottom boom section to horizon

$$\alpha = O_1Ox - \left(O_1OC_2 + C_2OC_8\right). \tag{6}$$

Values OA_1, OA_2 and OA_5 has being determined as hypotenuses of a triangles OA_1B_1, OA_2B_2 and OA_5B_5:

$$OA_1 = \sqrt{OB_1^{\,2} + A_1B_1^{\,2}}\ ; \tag{7}$$

$$OA_2 = \sqrt{OB_2^{\,2} + A_2B_2^{\,2}}\ ; \tag{8}$$

$$OA_5 = \sqrt{OB_5^{\,2} + A_5B_5^{\,2}}\ . \tag{9}$$

After that the values of angles A_1OB_1, A_2OB_2, A_5OB_5 have been determined:

$$A_1OB_1 = \mathrm{arctg}\left(\frac{A_1B_1}{OB_1}\right); \tag{10}$$

$$A_2OB_2 = a\tan\left(\frac{A_2B_2}{OB_2}\right); \tag{11}$$

$$A_5OB_5 = a\tan\left(\frac{A_5B_5}{OB_5}\right). \tag{12}$$

The angles C_2Ox, A_1Ox, A_2Ox, A_5Ox have being determined by dependencies

$$C_2Ox = C_2OC_8 + \alpha\ ; \tag{13}$$

$$A_1Ox = A_1OB_1 + \alpha\ ; \tag{14}$$

$$A_2Ox = A_2OB_2 + \alpha\ ; \tag{15}$$

$$A_5Ox = A_5OB_5 + \alpha\ . \tag{16}$$

It allowed to calculate the coordinates of points C_2, A_1, A_2, A_5:

$$xC_2 = OC_2 \cos(\mathrm{C_2O}\,x)\ ; \tag{17}$$

$$yC_2 = OC_2 \sin(\mathrm{C_2O}\,x)\ ; \tag{18}$$

$$xA_1 = OA_1 \cdot \cos(A_1Ox)\ ; \tag{19}$$

$$yA_1 = OA_1 \cdot \sin(A_1Ox)\ ; \tag{20}$$

$$xA_2 = OA_2 \cdot \cos(A_2Ox)\ ; \tag{21}$$

$$yA_2 = OA_2 \cdot \sin(A_2Ox)\ ; \tag{22}$$

$$xA_5 = OA_5 \cdot \cos(A_5Ox)\ ; \tag{23}$$

$$yA_5 = OA_5 \cdot \sin(A_5Ox)\ . \tag{24}$$

The coordinates of A_6 point (hinge stock of hydrocylinder management of upper boom section) is determined as coordinates points of intersection of the circle radius A_1A_6 with the center in point A_1 and the circle radius A_5A_6 with the center in point A_5:

$$\left.\begin{aligned} (x - xA_1)^2 + (y - yA_1)^2 = (A_1A_6)^2 \\ (x - xA_5)^2 + (y - yA_5)^2 = (A_5A_6)^2 \end{aligned}\right\} \tag{25}$$

The system of equations (25) has two solutions. For further calculations the pair of coordinates xA_6 and yA_6, where yA_6 has larger value, is being selected,.

Because coordinates of the points A_2 and A_6 are known, the length of segments A_2A_5 and $A_5A_6$is being calculated as:

$$A_2A_5 = \sqrt{\left(xA_2 - xA_5\right)^2 + (\mathrm{y}A_2 - \mathrm{y}A_5)^2}\ ; \qquad (26)$$

$$A_5A_6 = \sqrt{\left(xA_5 - xA_6\right)^2 + (\mathrm{y}A_5 - \mathrm{y}A_6)^2}\ . \qquad (27)$$

Then the values of angles A_5A_6x and $A_3A_6A_5$ have been calculated

$$A_3A_6A_5 = a\cos\left(\frac{A_3A_6^{\,2} + A_5A_6^{\,2} - A_3A_5^{\,2}}{2 \cdot A_3A_6 \cdot A_5A_6}\right). \qquad (28)$$

The angle A_3A_6x has been determined from the angles A_5A_6x and A_3A_6A:

$$A_3A_6x = A_3A_6A_5 + A_5A_6x\ . \qquad (29)$$

It allows to determine the coordinates of point A_3:

$$yA_3 = yA_6 + A_3A_6 \cdot \sin\left(A_3A_6x\right); \qquad (30)$$

$$xA_3 = xA_6 + A_3A_6 \cdot \cos\left(A_3A_6x\right). \qquad (31)$$

The angle $O_2A_5A_3$ has been determined from triangle $O_2A_5A_3$:

$$O_2A_5A_3 = a\cos\left(\frac{O_2A_5^{\,2} + A_3A_5^{\,2} - O_2A_3^{\,2}}{2 \cdot O_2A_5 \cdot A_3A_5}\right). \qquad (32)$$

Then the values of angles A_3O_5x and O_2A_5x have been calculated:

$$A_3A_5x = a\sin\left(\frac{yA_3 - yA_5}{A_3A_5}\right); \qquad (33)$$

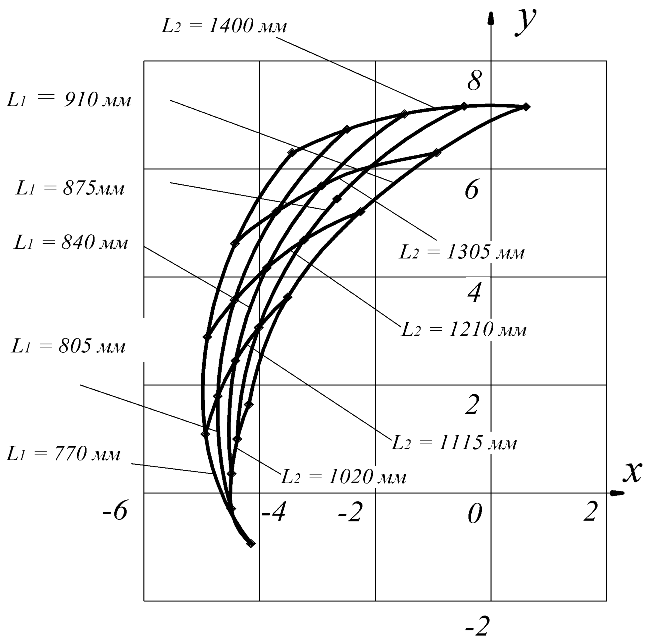
$$O_2A_5x = O_2A_5A_3 + A_3A_5x\ . \qquad (34)$$

Finally, the coordinates of upper boom section have been found:

$$xO_2 = xA_5 + O_2A_5 \cdot \cos(O_2A_5x); \qquad (35)$$

$$yO_2 = yA_5 + O_2A_5 \cdot \sin(O_2A_5x)\ . \qquad (36)$$

In result service area of machine (picture 2) has been obtained, where L_1 – length of hydrocylinder management bottom boom section; L_2 – length of hydrocylinder management upper boom section.



Picture 2 – Service area of AHH

Experimental part

To verify the obtained analytical solution of the kinematic AHH problem on ESPB of HNAHU, the series of experiments on two-section AHH, making rotatory movements, has been held. Angular position of AHH boom section was measured by digital electronic goniometer Bosch PAM 220, that has measurement error 0,2°.

The results of AHH mechanism position's calculations have been verified experimentally. For different values of nomination stocks of hydrocylider management bottom mechanism section, angle of inclination of the upper boom section has being determined.

Some results of verifying for upper and bottom boom section are shown in table 1 and table 2, accordingly, and in picture 3. As we can see from the table 1, 2, obtained solution is true: in all cases but one, relative error of determining AHH position by analytical and experimental methods is less than 1%.

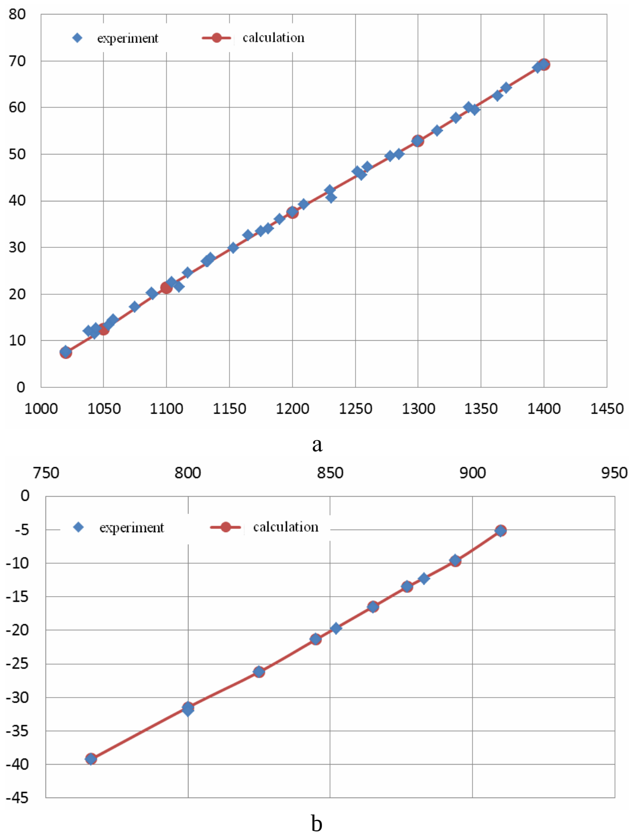
Table 1
Comparison of the calculation results of location upper boom section with experimental data

Length of hydrocylinder management upper boom section	The angle of inclination upper boom section, degrees		Relative error, %
	Calculation	Experiment	
1020	7,47	7,5	0,40
1050	12,47	13,0	4,08
1100	21,44	21,6	0,74
1200	37,56	37,6	0,11
1300	52,8	52,8	0,00
1400	69,3	69,2	-0,14

Table 2

Comparison of the calculation results of location bottom boom section with experimental data

Length of hydrocylinder management bottom boom section	The angle of inclination bottom boom section, degrees		Relative error, %
	Calculation	Experiment	
766	- 39,18	- 39,2	- 0,05
800	- 31,47	- 31,5	- 0,10
825	- 26,2	- 26,2	0,00
845	- 21,35	- 21,3	0,23
865	- 16,48	- 16,6	- 0,73
877	- 13,55	- 13,5	0,37
894	- 9,65	- 9,6	0,52
910	- 5,16	- 5,2	- 0,78



a – upper section, b – bottom section

Picture 3 – Calculation dependences of the angular positions of AHH boom section on nomination of stocks and experimental data

Ferthermore, from the picture 3 we can see that dependences of the angular positions of AHH boom section on nomination of executive hydrocylinders' stocks are practically linear, that greatly facilitates the synthesis of control system.

Conclusions

Improving the efficiency and safety of exploitation is relevance problem, that can be solved by introducing appropriate ACS only. One of the first stages of this ACS is the solution of kinematic problem that consists of determining position of mechanism nodal points. In this article the analytical solution of specified problem has been obtained, its adequacy has been confirmed experimentally.

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