IRSTI 55.03.14 DOI: https://doi.org/10.26577/JMMCS.2023.v118.i2.08

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THE CRANK-SLIDER MECHANISM FUNCTIONALITY

In this article present a new method for investigating the functionality of the crank-slider mechanism for a given coefficient of change in the average speed of the slider and the optimal transmission angle to ensure the most outstanding transfer of force from the input link to the working element (output link). When implementing the technological process on crank presses, it is necessary to provide a predetermined working cycle of the slider motion: fast lifting, dwell and slow lowering. This mechanism allows for a slow lowering of the working link in the load phase and a fast lifting in the unloading phase of the crank press's working body. Based on the above method developed a program in the Delphi 7 visual system. Delphi 7 allows you to quickly and easily develop effective applications, including database applications. The system has advanced capabilities for creating a user interface, a wide range of functions, methods and properties for solving applied computational problems. The system has advanced debugging tools that facilitate the development of applications, which allows determining the parameters of the synthesized crank-slider mechanism by the optimal pressure angle and conducting a kinematic analysis of the movement of the links in the dialogue mode.
Key words: crank press, Delphi, lever mechanism, automatic press, hybrid press system.

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Қосиінді-жүгірткі механизмінің функционалды мүмкіндіктері

Бұл жұмыста күштің кіріс буынынан жұмыс органына (шығыс буынына) ең көп берілуін қамтамасыз ету үшін жүгірткінің орташа жылдамдығының берілген өзгеру коэффициентіне және берілудің оңтайлы бұрышына сәйкес қосиінді-жүгірткі механизмінің функционалды мүмкіндігін зерттеудің жаңа әдісі ұсынылады. Технологиялық процесті қосиінді престерде жүзеге асыру кезінде жұмыс сырғытпасының қозғалысының берілген циклограммасын қамтамасыз ету қажет: жылдам көтерілу, кідіру, баяу түсіру. Бұл механизм жүктеме фазасында жұмыс байланысын баяу төмендетуге және қосиінді престің жұмыс бөлігінің түсіру фазасында тез көтерілуге мүмкіндік береді. Жоғарыда келтірілген әдіс негізінде Delphi 7 визуалды жүйесінде бағдарлама жасалды. Delphi 7 тиімді қосымшаларды, соның ішінде дерекқормен жұмыс істеуге арналған қосымшаларды тез және ыңғайлы дамытуға мүмкіндік береді. Жүйеде пайдаланушы интерфейсін құру үшін дамыған мүмкіндіктер, қолданбалы есептеу және есептеу мәселелерін шешуге арналған көптеген функциялар, әдістер мен қасиеттер бар. Жүйеде қосымшаларды әзірлеуді жеңілдететін дамыған жөндеу құралдары бар, ол синтезделген қосиінді-жүгірткі механизмінің параметрлерін қысымның оңтайлы бұрышында анықтауға және диалог режимінде байланыстардың қозғалысына кинематикалық талдау жүргізуге мүмкіндік береді.

Түйін сөздер:қосиінді пресс, Delphi, рычаг механизмі, пресс-машина, гибридті пресс жүйесі.

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Функциональные возможности кривошипно-ползунного механизма

В данной работе предлагается новый метод исследования функциональной возможности кривошипно-ползунного механизма по заданному коэффициенту изменения средней скорости ползуна и оптимальному углу передачи для обеспечения наибольшей передачи усилия от входного звена к рабочему органу (выходному звену). При реализации технологического процесса в кривошипных прессах нужно обеспечить заданную циклограмму перемещения рабочего ползуна: быстрый подъем, выстой, медленное опускание. Данный механизм позволяет осуществить медленное опускание рабочего звена на фазе нагрузки и быстро подниматься на фазе разгрузки рабочего органа кривошипного пресса. На основании вышеприведенного метода разработана программа в визуальной системе Delphi 7. Delphi 7 позволяет быстро и удобно разрабатывать эффективные приложения, включая приложения для работы с базами данных. Система имеет развитые возможности по созданию пользовательского интерфейса, широкий набор функций, методов и свойств для решения прикладных расчетно – вычислительных задач. В системе имеются развитые средства отладки, облегчающие разработку приложений, которая позволяет определить параметры синтезируемого кривошипно-ползунного механизма по оптимальному углу давления и проводить кинематический анализ перемещения звеньев в диалоговом режиме.

Ключевые слова: кривошипный пресс, Delphi, рычажный механизм, пресс-автомат, гибридная пресс-система.

1 Introduction

For providing a fast lifting (forward stroke) and slow lowering (reverse stroke) of the working slider, it is necessary to synthesize the crank-slider mechanism according to the coefficient of change in the average speed of the output link [1]. It also solves the task of providing the optimal pressure angle or angle of transmission to ensure the most excellent transfer of force from the input link to the working body (output link), satisfying simple dynamic requirements.

The synthesis of four-link simple mechanisms according to the given positions of the links or the coefficient of change in the average speed belongs to the classical tasks considered by the graphical method [2] and analytical methods [3–5]. In known works [3–5], authors consider the synthesis method by the coefficient of change in the average speed applied to the four-link hinge and rocker mechanism. The authors study the synthesis of the crank-slider mechanism according to two positions of the links [5]. Still, they do not consider the change in the coefficient of the output link's average speed separately. It should be noted that based on the method of blocked zones in the theory of mechanisms, we have obtained solutions of a large number of other tasks of synthesis of four and six-link flat linkages [4, 6, 7].

Foremost, researchers consider the synthesis of crank presses in other settings, particularly the synthesis of a crank press based on a more complex structure or to ensure the working link's dwell [8–11]. Defined work [8] considers the solution to this task at the expense of control, for which additional latitude is introduced into the kinematic chain; they are called hybrid press systems. This research [8] considers a seven-link linkage with two degrees of latitude (2 DOF), in which one generalized coordinate is changed based on a DC power motor (to implement the primary technological process), the second based on a servo motor to provide a cyclogram of the technological process.

In this research propose a new method for synthesizing the crank-slider mechanism of a press machine for a given coefficient of change in the average speed of the slider and the optimal pressure angle to ensure the most significant transfer of force from the input link to the working element (output link). Based on solving this task the authors created a software package for the synthesis of a crank-slider mechanism that meets the preliminary dynamic requirements [4].

2 Material and methods

2.1 Derivation of the basic equations

Figure 1 presents a kinematic diagram of a crank press. The following designations of the coordinates and dimensions of the links were introduced: a - the crank length; b - length of parallel connecting rod; φ - angular coordinate of the crank; ψ - angular (ν - pressure angle) coordinate of the connecting rod; θ is the angle between two positions of the connecting rod at two extreme positions of the slider; S - linear coordinate of the slider; e is the eccentricity of the slide, i.e., deviation of the trajectory of the center of gravity of the slider from the axis Ox. Let the crank swing angle and the slider stroke φ_m and S_m be given, where $0 < \varphi_m < 2\pi$ while φ_m - the angular interval of the crank positions corresponding to the slow lowering (reverse stroke) of the working slider, on the interval $(2\pi - \varphi_m)$, a fast lifting (forward stroke) of the slider.

We can write the equations of the kinematics of the mechanism

$$\begin{cases} a\cos\varphi - b\cos\psi = S \\ a\sin\varphi - b\sin\psi = e \end{cases} \tag{1}$$

In the process of synthesis, according to an angle φ_m given value, the coefficient of change in the average speed of the slide can be set equal to

$$K = \frac{\varphi_m}{2\pi - \varphi_m} > 1 \tag{2}$$

The synthesis of the mechanism is to determine the dimensions of the mechanism a, b, and eccentricity e according to the given parameters φ_m and S_m, which provide the optimal pressure angle ν_{ext}.

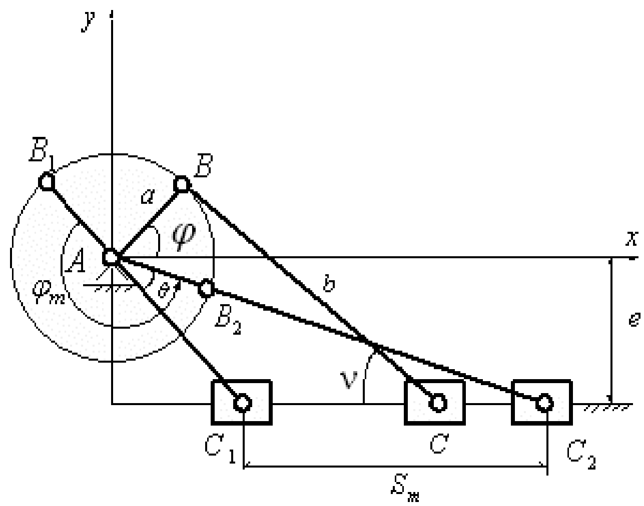

Figure 1: Kinematic diagram of the mechanism

From the triangle $\triangle\ AC_1C_2$, according to the cosine theorem, we can write the following ratio

$$S_m{}^2 = (b-a)^2 + (b+a)^2 - 2*(b-a)(b+a)*\cos\theta \tag{3}$$

Considering that $\theta = \varphi_m - \pi$ and after transformation, we get

$$S_m{}^2 = 2*(b^2 - a^2)(1+\cos\theta) + 4a^2 \tag{4}$$

Substituting into equations (3) the ratios $(1+\cos\theta) = 2\cos^2\frac{\varphi_m}{2}$ and $\sin^2\frac{\varphi_m}{2} + \cos^2\frac{\varphi_m}{2} = 1$ and introducing the notation $x = S_m/2$, $z = \varphi_m/2$ we have an equation in the form

$$x^2 = a^2\sin^2 z + b^2\cos^2 z \tag{5}$$

On the other hand, from right-angled triangles (Figure 1), for the value x, you can write

$$2x = \sqrt{(a+b)^2 - e^2} - \sqrt{(a-b)^2 - e^2} \tag{6}$$

further from equation (5), we find e^2

$$e^2 = a^2 + b^2 - x^2 - \frac{a^2b^2}{x^2} \tag{7}$$

Substituting a^2 from equation (4) into equation (6), we finally obtain

$$e = \pm\frac{\cot z}{x}(b^2 - x^2) \tag{8}$$

The sign $\pm$ in the last formula means that, due to symmetry, we can choose the eccentricity, both negative, i.e., the guide can run both above the axis and below it.

3 Synthesis of the mechanism from the condition of the extremum of the pressure angle

The condition for the optimization synthesis is the maximum pressure angle ν_{ext}. If we divide the right and left sides of equation (4) by x^2 , we obtain the dimensionless equation $1 = a^2 \sin^2 z + b^2 \cos^2 z$, wherein what follows we will assume that a, e and b are dimensionless parameters with scale factors $x = S_m/2$. Then, concerning dimensionless quantities, equations (4) and (7) make up the system

$$\begin{cases} a^2 \sin^2 z = 1 - b^2 \cos^2 z, b > \frac{1}{|\cos z|} \\ e = \pm(b^2 - 1)\cot z \end{cases} \quad (9)$$

From the second equation of system (1), we have

$$\sin\nu = \frac{e + a\sin\varphi}{b} \quad (10)$$

From equation (9), it can be seen that the largest value of the pressure angle is achieved with the vertical position of the crank, i.e.

$$\sin\nu_{ext} = \frac{a + |e|}{b}, b > a + |e|, \quad (11)$$

in this case, the inequality in formula (10) is the condition for the crank's existence [5].

Substituting equation (8) into (10), we obtain the maximum pressure angle dependence as a function of the sought parameter b.

$$\sin\nu_{ext} = \frac{\sqrt{1 - b^2\cos^2 z} + |(b^2 - 1)\cos z|}{b \sin z} \quad (12)$$

The necessary condition for the extremum of function (11) is the equality to zero of the derivative of the right-hand side of b leads to the following bicube equation

$$b^2 \cos^2 z + b^4 \cos 2z + b^2(\cos^2 z - 2) + \tan^2 z = 0 \quad (13)$$

After the appropriate transformation, equation (12) can be represented as

$$b^2(b^2 + 1)[\cos^2 z(b^2 + 1) - 1] - (b^2 - \tan^2 z) = 0 \quad (14)$$

or taking into account the ratio $\cos^2 z = 1/(1 + \tan^2 z)$

$$[b^2(b^2 + 1)\cos^2 z - 1](b^2 - \tan^2 z) = 0 \quad (15)$$

The solution to the equation $b^2 - \tan^2 z = 0$ corresponds to the maximum pressure angle, and its value is known (10).

According to (13), other extreme values ν_{ext} must satisfy the following biquadratic equation

$$b^4 \cos^2 z + b^2 \cos^2 z - 1 = 0 \tag{16}$$

Considering that for b^2 the equation is quadratic, and with its satisfying solution constraints (9) and (10), we can write

$$b = \sqrt{\frac{1}{2} * (\sqrt{1 + \frac{4}{\cos^2 z}} - 1)} \tag{17}$$

Substitute (15) into equations (8), after which, for the remaining relative values of the mechanism parameters, we can write functions of, $z = \varphi_m/2$

$$a = \frac{1}{2\sin z}(\sqrt{\cos^2 z + 4} - |\cos z|), e = \frac{1}{2\sin z}(\sqrt{\cos^2 z + 4} - 3|\cos z|) \tag{18}$$

Also, based on (8), there are obvious ratios between the parameters of the mechanism a, e and b

$$a = b^2|\cot z|, e = a - |\cot z|, \frac{1}{b^2} = \frac{a-e}{a} \tag{19}$$

4 Results and discussion

Based on formula (11), we construct a graph of the extreme pressure angle $\nu_{ext} = \nu_{ext}(z)$. Figure 2 presents the results. Based on formulas (15) and (16), we construct graphs of dependences of dimensionless parameters $b = b(\psi_m), a = a(\psi_m), e = e(\psi_m)$ at $S_m = 2$.

Analysis of the graphs in Figures 2 and 3 shows that when searching for the mechanism parameters, there are singular points for $\varphi_m = 0; \pi, \pi$ when the dimensions of the mechanism increase indefinitely. All graphs are symmetrical about the vertical $\varphi_m = \pi$.

For $\varphi_m = 0$ and $\varphi_m = 3\pi/2$, the links' dimensions are the same $a = b = 1$, and the eccentricity is $e = 0$, which means we obtain the case of a central crank-slider mechanism.

When $\varphi_m = \pi$ the size of the crank is $a = 1$, and the size of the connecting rod tends to infinity. For these exceptional cases, we can accept the recommendations noted in the textbook (Frolov, Popov, etc. 2003). Based on the previous analysis and from the graph for the pressure angle, we can conclude that the swing angle of the crank should belong to the intervals $\varphi_m \in (\pi/2, \pi)$ and $\varphi_m \in (\pi, 3\pi/2)$. It is advisable to use the second interval in the design because the working stroke exceeds the idle speed, which leads to an increase in the efficiency of this mechanism.

Based on the above method, we have developed a program in the Delphi 7 visual system [1], which allows the optimal pressure angle to determine the synthesized crank-slider mechanism parameters. The initial data for design are the crank swing angle φ_m or the coefficient of change in the slider average speed K and the maximum stroke of the slider S_m. To simplify calculations and analysis of constraints, we reduced all parameters to dimensionless form according to formulas (8) and (11), i.e., and it is assumed that the reduced stroke $\overline{S_m} = 2$, $(x = 1)$ is given, and all dimensions are determined depending on this parameter. After pressing the "Synthesis"button, the synthesis parameters of the mechanism a, b, e are displayed in dimensional form, depending on the set stroke S_m, extreme pressure angle ν_{ext}, plan of the mechanism position for angles $\varphi \in [\psi_0, \psi_0 + \psi_m]$, $\psi_0 = \pi - \arccos[e/(b-a)]$, and also displays the graphs of the kinematic parameters for the slider S, S', S'' and the pressure angle ν, which were calculated by the following formulas

$$S = a\cos\varphi - b\cos\psi, \qquad \psi = \arcsin(\frac{e + a\sin\varphi}{b} \tag{20}$$

$$S' = b\sin\psi * \psi' - a\sin\varphi, \qquad \psi' = \frac{a\cos\varphi}{b\cos\psi} \tag{21}$$

$$S'' = b\cos\psi(\psi')^2 + b\sin\psi * \psi'' - a\cos\varphi, \qquad \psi'' = \frac{b\sin\psi(\psi')^2 - a\sin\varphi}{b\cos\psi} \tag{22}$$

$$\nu = \arcsin(\frac{e + a\sin\varphi}{b}) \tag{23}$$

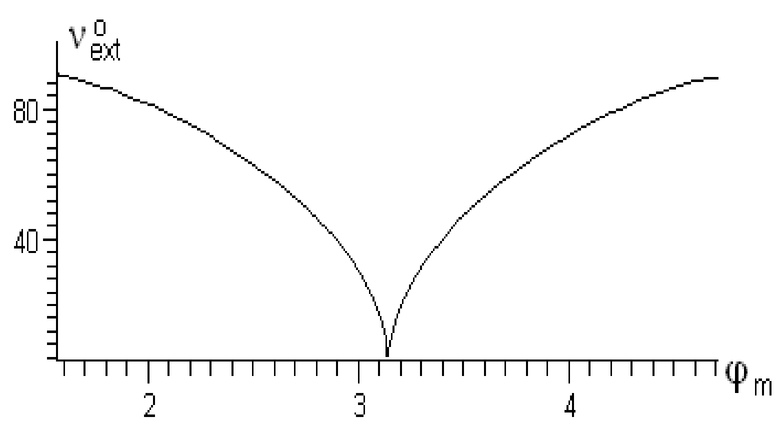

Figure 2: Extreme pressure angle graph

With a given coefficient of change in the average speed equal to $K = 1,4$ and the stroke of the slider $S_m = 70cm$, the following optimal values of the parameters were obtained

$\varphi_m = 210°$, $a = 31,85cm$, $b = 64,5cm$, $e = 22,47cm$, $\nu_{ext} = 57,36°$ of a crank press. We measured the S value from the ordinate axis. The "Movement" button demonstrates the crank-slider mechanism's operation for a full rotation of the crank rotation. The "Table" button is intended for the tabular display of the kinematic parameters S, ψ, and the pressure angle depending on the angle of rotation of the crank φ in the working stroke section.

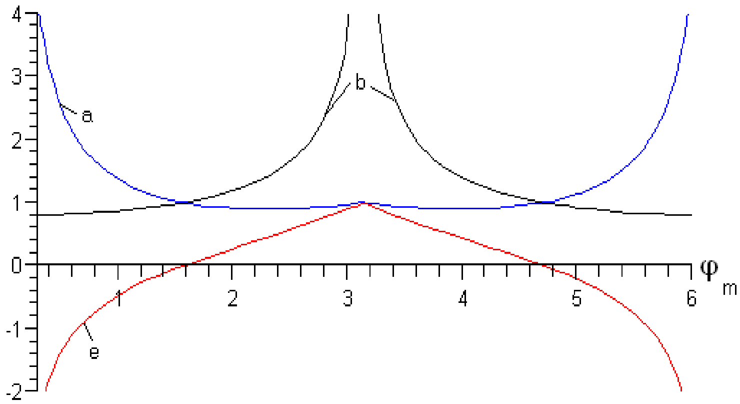

Figure 3: Graphs of functions a, e and b

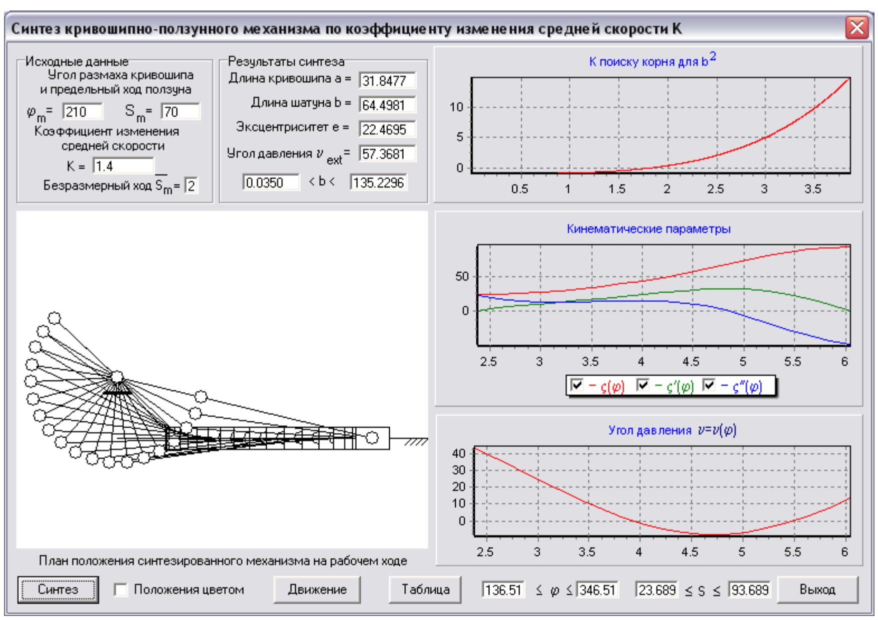

Figure 4: The application dialog box in the Delphi visual system (Tuleshov and Drakunov 2006)

The dialog box's upper panel displays the function's graph (14) for the biquadratic equation relative to the connecting rod b. In the absence of options for solving the synthesis problem, corresponding error messages are displayed, or recommendations are proposed to select the mechanism's appropriate synthesis parameters. The "Exit" button is used to close the work with this application.

5 Conclusion

A new method has been developed for studying the functionality of a crank-slider mechanism according to a given coefficient of change in the average speed of the slider and the optimal transmission angle to ensure the greatest transfer of force from the input link to the working body (output link). And also, a software package for the synthesis of a crank-slider mechanism has been developed that meets the preliminary dynamic requirements. The parameters of the synthesized crank-slider mechanism are determined by the optimal pressure angle in the Delphi visual system and a kinematic analysis of the movement of the links in the interactive mode is carried out.

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