IRSTI 55.30.03, 55.30.31, 55.30.13 DOI: https://doi.org/10.26577/JMMCS2023v119i3a6

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EFFECTIVE SOLUTION OF THE PROBLEM OF DIRECT KINEMATICS FOR DRILLING ROBOT-MANIPULATOR WITH FOUR DEGREES OF FREEDOM IN THE MAPLE PROGRAM

Today, construction machines are widely used, which can be used in hazardous and toxic working environments, in other adverse environments, and in places where it is very difficult for a human operator to control the machine. At the same time, in the current difficult economic situation, it is important to increase the productivity of these construction machines in the mining, construction, and manufacturing sectors. Due to the versatility and convenience of hydraulically driven manipulators among construction machines, they occupy the majority of equipment used in mining or construction work. Vibration machines are used in many technological processes for the removal of hard rocks and other materials in the work performed by hydraulic excavators. This paper considers a hydraulically driven drilling robot with four degrees of freedom. These are machines and equipment based on lever mechanisms of variable structures, which have a number of advantages over analogs. The use of mechanisms of variable structures significantly increases the reliability of vibration shocks, their design is simple and does not require imported materials and components. This is especially important for machines operating in difficult mountain conditions. Under the above operating conditions, semi-automatic or fully computer-controlled machines can work successfully and efficiently. To do this, it is important to understand the kinematics of this machine. therefore, the article describes the sequence of actions required to solve the direct problem of kinematics directed at a drilling robot with four degrees of freedom.
Key words: Direct kinematics, hydraulic drive, drilling robot, lever mechanism, excavator, vector expression.

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Maple бағдарламасында төрт еркіндік дәрежесіне ие бұрғылау робот-манипуляторы үшін тікелей кинематика мәселесін тиімді шешу

Қазіргі таңда жұмыс жасауға қауіпті және жұмыс жасау ортасы улы, басқада ауа-райы қолайсыз орталада және адам операторының машинамен жұмыс істеуі өте қиын лас жерлерде пайдалануға болатын құрылыс машиналары кең қолданысқа ие. Сонымен қатар қазіргі уақытта күрделі экономикалық жағдайда, сол құрлыс машиналарының тау-кен, құрылыс, өндіріс саласындағы жұмыстарының өнімділігін арттыру өте маңызды. Құрлыс машиналары ішінде гидравликалық жетекті манипуляторлардың әмбебаптығы мен ыңғайлылығына байланысты тау-кен өндірісі немесе құрылыс жұмыстарының көпшілігінде жұмыс істейтін техникалардың басым бөлігін алады. Гидравликалық экскаваторлар орындайтын жұмыстардың ішінде діріл әсер ететін машиналар қатты тау жыныстарын және басқа материалдарды жою үшін көптеген технологиялық процестерде қолданылады.

Бұл жұмыста гидравликалық жетекті төрт еркіндік дәрежесі бар бұрғылау роботы қарастырылады. Бұл аналогтарға қарағанда бірқатар артықшылықтарға ие ауыспалы құрылымдардың интрегті механизмдеріне негізделген машиналар мен жабдықтар болып табылады. Ауыспалы құрылымдардың механизмдерін қолдану діріл соққыларының сенімділігін едәуір арттырады, олардың дизайны қарапайым, жәнеде импортталған материалдар мен компоненттерді қажет етпейді. Бұл күрделі тау жағдайында жұмыс істейтін машиналар үшін ерекше маңызды. Жоғарыда аталған жұмыс жағдайларында жартылай автоматты немесе толық компьютерлік басқарылатын машиналар жұмысты сәтті және тиімді орындалуы мүмкін. Бұл үшін бұл машинаның кинематикасын түсіну маңызды. сондықтан мақалада төрт еркіндік дәрежесі бар бұрғылау роботына бағытталған кинематиканың тура есебін шешу үшін қажетті әрекеттер тізбегін сипаттады.
Түйін сөздер: Тура кинематика, гидравликалық жетек, бұрғылау роботы, рычаг механизмі, экскаватор, векторлық өрнектеу.

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Эффективное решение задачи прямой кинематики для бурового робота-манипулятора с четырьмя степенями свободы в программе Maple

В настоящее время широкое применение имеют строительные машины, которые могут использоваться в опасных для работы и токсичных рабочих средах, в других неблагоприятных погодных условиях и в грязных местах, где человеку-оператору очень трудно работать с машиной. Кроме того, в настоящее время в сложных экономических условиях очень важно повысить производительность работ машин этого же континента в горнодобывающей, строительной, производственной сферах. Внутри наземных машин из-за универсальности и удобства манипуляторов с гидравлическим приводом большая часть техники используется для большинства горных или строительных работ. Среди работ, выполняемых гидравлическими экскаваторами, вибрационные машины используются во многих технологических процессах для удаления твердых пород и других материалов. В этой работе рассматривается буровой робот с четырьмя степенями свободы с гидравлическим приводом. Это машины и оборудование, основанные на рычажных механизмах переменных конструкций, которые имеют ряд преимуществ перед аналогами. Применение механизмов переходных конструкций значительно повышает надежность виброударов, конструкция которых проста и не требует импортных материалов и комплектующих. Это особенно важно для машин, работающих в сложных горных условиях. В вышеупомянутых условиях работы полуавтоматические или полностью управляемые компьютером машины могут выполнять работу успешно и эффективно. Для этого важно понимать кинематику этой машины. поэтому в статье описана последовательность действий, необходимая для решения прямой задачи кинематики, направленной на бурового робота с четырьмя степенями свободы.

Ключевые слова: Прямая кинематика, гидравлический привод, буровой робот, рычаг механизм, экскаватор, векторное выражение.

1 Introduction

Hydraulic excavators are one of the main machines used in the mining industry. Such machines are widely used all over the world in the harsh environment of opencast mining. for example, CIS, Australia, Canada, South Africa, South America. Air temperature in these environments from -40C to +55C, humidity of 95% of condensed air, shock loads up to 5 g on the mechanism, as well as oscillation resistance at a frequency of 2-6 Hz up to 2 g are the main difficulties for the duration of the operating cycle is. In addition, manufacturers will increase the requirements for these machines in terms of increasing productivity, efficiency and safety. Therefore, excavators are gradually evolving into complex mechanical electro-hydraulic systems, for which it is more important to develop modeling, both in terms of design and automation [1].

Already, scientists have made significant progress in researching robotic excavators. Cui et al [2]. The spatial kinematic characteristics of the telescopic robot excavator are analyzed and verified on the basis of a virtual prototype and a physical prototype. analyzed the trajectory planning and control system based on the kinematic model. In order to operate a hydraulic excavator, it is important to understand the kinematics and dynamics of the excavator. Dhaval et al [3]. has discussed various reviews related to the kinematics of an excavator machine to achieve the stated goal, which Kinematic modeling helps to understand the properties of a hydraulic excavator machine and increase performance. The current trend in the development of workflow control systems is associated with the robotization of excavators, so it is advisable to use appropriate methods of robotics in the development of such systems [4]. Krivo obtained kinematic and dynamic models of the excavator with great accuracy, as well as used PD and PID controllers to control the work process [5]. Jomartov A., Tuleshov A. [6] proposed to develop a vector method for determining reactions in kinematic pairs, as well as the balancing moment, which significantly simplified the problem of kinetostatic analysis of complex bonds. He proposed to implement algorithms on a computer using the analytical computing package of the Maple program.as a result, the results of solving the problem of kinetostatic analysis were finally obtained in vector form.

Advantages of the mechanism considered in the article in comparison with analogs: in the presence of machines and equipment based on lever mechanisms of variable structures. The use of mechanisms of variable structures significantly increases the reliability of vibration shocks of impact hammers. The course of kinematic calculation was based on the analytical method of a closed circuit, in which the selected vector system is considered as geometric polygons with zero sum [7]. In comparison with the D-H method, when using the classical D-h method, it is possible to set the coordinate system on the continuation of the axis, and finally there is a situation when our theoretical model is incompatible with the real manipulator. On the contrary, if we use the method of constructing a coordinate system based on the basic coordinate transformation, this method is much simpler, without theoretical errors, intuitive, and also a faster method for calculating direct kinematics [8]. Xuewen Yang et al. In his work, a geometric method of kinematics was used for the Delta parallel robot, as well as a speed control method based on the PO controller. The peculiarity of this geometric method is the reduction of calculation time and a significant increase in accuracy and efficiency [9]. Based on this evidence, we solved the direct kinematics of the drilling robot using the geometric method.

2 Materials and methods

2.1 Robot design

Improving the controllability of the manipulator has a direct impact on increasing efficiency and reducing costs. First, the structure and operating conditions of the drilling robot with four degrees of freedom are analyzed. The lever mechanism, created by two hydraulic cylinders, helps to ensure the stability of the mechanism, as the joints are connected in a triangular pattern. The structure of our drilling robot consists of: AE and FG fixed arm (lever), BD and CF hydraulic drive and a drill mounted on G.

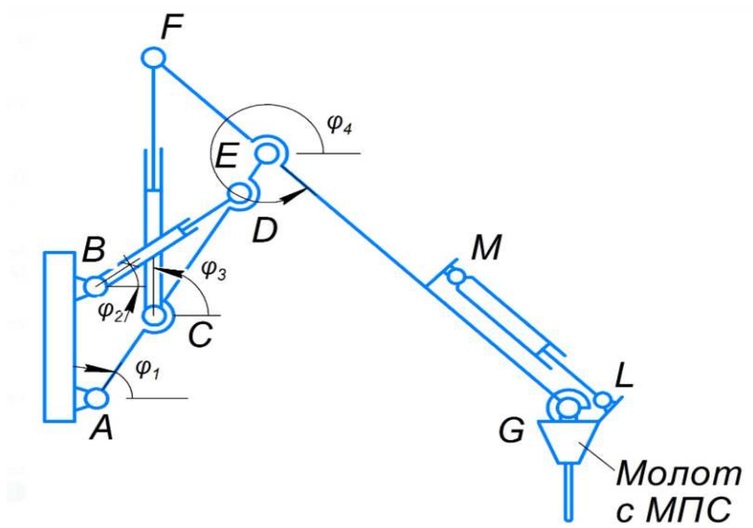


Figure 1: 2D design of a drilling robot in the plane

2.2 Goals and objectives

At the first stage of designing a manipulator control system, it is necessary to consider its kinematics, ie. As a function of time we find the position of the manipulator in space and the relationship between the generalized coordinates and the location of the drill.

The purpose of this work is to study the kinematics of the manipulator using the program Maple. To do this, the following tasks are solved at work:

- determine the positions, angular and linear movements of the joints of the mechanism of motion, construct trajectories and find areas of change of its individual moving points;
- determine the speed of individual points and joints of the mechanism;
- to determine the acceleration of individual points and joints of the mechanism;
- creating a model of the manipulator in Maple;
- creation of 3D model of the manipulator in Inventor;
- solve direct and inverse problems of kinematics of hydraulic manipulator;
- planning the trajectories of the manipulator when moving the drilling point from one point in space to another.

2.3 Direct kinematics

We solve the direct problem of kinematics, according to the dependence of the generalized $s = f(\varphi)$ coordinates $\varphi = (\varphi_1; \varphi_2; \varphi_3; \varphi_4)$ (angles of rotation of the corresponding joints of powerful robot manipulators) and find the location of the drilling installation point. We solve the direct problem of kinematics analytically using the geometric method.

To determine the positions, velocities and accelerations of the joints of the mechanism, we construct the vector equations of the closed chain ΔAEG, the closed chain $ABDEG$ and the closed chain $ACFG$:

$$\begin{cases} \vec{l}_{AE} + \vec{l}_{EG} = \vec{r} \\ \vec{l}_{AB} + \vec{l}_{BD} + \vec{l}_{DE} + \vec{l}_{EG} = \vec{r} \\ \vec{l}_{AC} + \vec{l}_{CF} + \vec{l}_{FG} = \vec{r} \end{cases} \tag{1}$$

where $\vec{l}_i$ – is the vector expression of the corresponding links in the closed chain, $\vec{r}$ – is the vector value from the origin to the point G.
By projecting the vectors of equation (1) on the x and y coordinate axes, we obtain the equations describing the positions of the joints of the mechanism: We express the projections of the equation obtained on the x, y-axes obtained according to the closed chain ΔAEG as follows, where the slope angles are unknown:

$$\begin{cases} l_{AE} \cdot \cos\varphi_1 + l_{EG} \cdot \cos\varphi_4 = x_G \\ l_{AE} \cdot \sin\varphi_1 + l_{EG} \cdot \sin\varphi_4 = y_G \end{cases} \tag{2}$$

l_i – dimensions of the corresponding joints, φ_i – correct inclination angles, x_G, y_G – coordinates of the corresponding G-point obtained in accordance with the X, Y-axes.

We express the projections of the equation obtained on the x, y-axes obtained according to the closed chain $ABDEG$ as follows:

$$\begin{cases} l_{BD} \cdot \cos\varphi_2 + l_{DE} \cdot \cos\varphi_1 + l_{EG} \cdot \cos\varphi_4 = x_G \\ l_{AB} + l_{BD} \cdot \sin\varphi_2 + l_{DE} \cdot \sin\varphi_1 + l_{EG} \cdot \sin\varphi_4 = y_G \end{cases} \tag{3}$$

where l_i – is the size of the corresponding joints, φ_i – is the angle of inclination, x_G, y_G – is the coordinate of the corresponding G-point on the x, y axes.
The projections of the equation obtained on the closed chain $ACFG$ on the x, y-axes are expressed as follows:

$$\begin{cases} l_{AC} \cdot \cos\varphi_1 + l_{CF} \cos\varphi_3 + l_{FG} \cos\varphi_4 = x_G \\ l_{AC} \cdot \sin\varphi_1 + l_{CF} \sin\varphi_3 + l_{FG} \sin\varphi_4 = y_G \end{cases} \tag{4}$$

where l_i – is the size of the corresponding joints, φ_i – is the angle of inclination, x_G, y_G – is the coordinate of the corresponding G-point on the x, y axes.

As a result, we obtain the trajectories and limits of change of all characteristic points of the mechanism. By modifying this system of equations, we can obtain the required values: φ_i – the formula for determining the angle of inclination:

$$\varphi_1 = \pm \arccos \frac{l_{AB}^2 + l_{AD}^2 - l_{BD}^2}{2 l_{AB} l_{AD}} \tag{5}$$

φ_1 – angle of inclination of the joint AE.

$$\varphi_2 = \pm arctg \frac{l_{AD} \cdot \cos \varphi_1 - l_{AB}}{l_{AD} \cdot \sin \varphi_1} \tag{6}$$

φ_2 – is the angle of inclination of the joint BD where the hydraulic cylinder is located.

$$\varphi_3 = \pm \arccos \frac{l_{CF}^2 + l_{CE}^2 - l_{EF}^2}{2 l_{CF} l_{CE}} \pm \arccos \frac{l_{AB}^2 + l_{AD}^2 - l_{BD}^2}{2 l_{AB} l_{AD}} \tag{7}$$

φ_3 – is the angle of inclination of the joint CF where the hydraulic cylinder is located.

$$\varphi_4 = \pm arctg \frac{l_{CE} \cdot \sin \varphi_1 - l_{CF} \cdot \sin \varphi_3}{l_{CE} \cdot \cos \varphi_1 - l_{CF} \cdot \cos \varphi_3} \tag{8}$$

φ_4 – angle of inclination FG.

Coordinates of contact points in the XOY plane:

Coordinates of the C-hinge with the plane

$$\begin{pmatrix} x_C \\ \\ y_C \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos \varphi_1 \\ \\ l_{AC} \cdot \sin \varphi_1 \end{pmatrix} \tag{9}$$

By differentiating by time 1.8, we obtain the projections of the velocity of point C on the x and y coordinate axes.

$$\begin{pmatrix} \dot{x}_C \\ \\ \dot{y}_C \end{pmatrix} = \begin{pmatrix} -l_{AC} \omega_1 \sin \varphi_1 \\ \\ l_{AC} \omega_1 \cos \varphi_1 \end{pmatrix} \tag{10}$$

and the speed of rotation of point C :

$$\nu_C = \sqrt{\dot{x}_c^2 + \dot{y}_C^2} = l_{AC} \omega_1 \tag{11}$$

By differentiating equations (10) we obtain the projections of the accelerations of point C on the x and y coordinate axes.

$$\begin{pmatrix} \ddot{x}_C \\ \\ \ddot{y}_C \end{pmatrix} = \begin{pmatrix} -l_{AC} \varepsilon_1 \sin \varphi_1 - l_{AC} \omega_1^2 \cos \varphi_1 \\ \\ l_{AC} \varepsilon_1 \cos \varphi_1 - l_{AC} \omega_1^2 \sin \varphi_1 \end{pmatrix} \tag{12}$$

Acceleration of point C

$$a_C = \sqrt{\ddot{x}_C^2 + \ddot{y}_C^2} = l_{AC} \sqrt{\varepsilon_1^2 + \omega_1^4} \tag{13}$$

Coordinates of the D-hinge with the plane

$$\begin{pmatrix} x_D \\ \\ y_D \end{pmatrix} = \begin{pmatrix} l_{AD} \cdot \cos\varphi_1 \\ \\ l_{AD} \cdot \sin\varphi_1 \end{pmatrix} \tag{14}$$

By differentiating in time (14), we obtain the projections of the velocity of the point D on the x and y coordinate axes.

$$\begin{pmatrix} \dot{x}_D \\ \\ \dot{y}_D \end{pmatrix} = \begin{pmatrix} -l_{AD}\omega_1 \sin\varphi_1 \\ \\ l_{AD}\omega_1 \cos\varphi_1 \end{pmatrix} \tag{15}$$

and the speed of rotation of point D :

$$\nu_D = \sqrt{\dot{x}_D^2 + \dot{y}_D^2} = l_{AD}\omega_1 \tag{16}$$

By differentiating equations (15) we obtain the projections of the accelerations of the point D on the x and y coordinate axes

$$\begin{pmatrix} \ddot{x}_D \\ \\ \ddot{y}_D \end{pmatrix} = \begin{pmatrix} -l_{AD}\varepsilon_1 \sin\varphi_1 - l_{AD}\omega_1^2 \cos\varphi_1 \\ \\ l_{AD}\varepsilon_1 \cos\varphi_1 - l_{AD}\omega_1^2 \sin\varphi_1 \end{pmatrix} \tag{17}$$

Acceleration of point D

$$a_D = \sqrt{\ddot{x}_D^2 + \ddot{y}_D^2} = l_{AD}\sqrt{\varepsilon_1^2 + \omega_1^4} \tag{18}$$

Coordinates of the E-hinge according to the plane

$$\begin{pmatrix} x_E \\ \\ y_E \end{pmatrix} = \begin{pmatrix} l_{AE} \cdot \cos\varphi_1 \\ \\ l_{AE} \cdot \sin\varphi_1 \end{pmatrix} \tag{19}$$

By differentiating by time (19), we obtain the projections of the velocity of the point E on the x and y coordinate axes.

$$\begin{pmatrix} \dot{x}_E \\ \\ \dot{y}_E \end{pmatrix} = \begin{pmatrix} -l_{AE}\omega_1 \sin\varphi_1 \\ \\ l_{AE}\omega_1 \cos\varphi_1 \end{pmatrix} \tag{20}$$

and the rotational speed of point E :

$$\nu_E = \sqrt{\dot{x}_E^2 + \dot{y}_E^2} = l_{AE}\omega_1 \tag{21}$$

By differentiating equations (20) we obtain the projections of the accelerations of the point E on the x and y coordinate axes.

$$\begin{pmatrix} \ddot{x}_E \\ \\ \ddot{y}_E \end{pmatrix} = \begin{pmatrix} -l_{AE}\varepsilon_1 \sin\varphi_1 - l_{AE}\omega_1^2 \cos\varphi_1 \\ \\ l_{AE}\varepsilon_1 \cos\varphi_1 - l_{AE}\omega_1^2 \sin\varphi_1 \end{pmatrix} \tag{22}$$

Acceleration of point E

$$a_E = \sqrt{\ddot{x}_E^2 + \ddot{y}_E^2} = l_{AE}\sqrt{\varepsilon_1^2 + \omega_1^4} \tag{23}$$

Coordinates of the F-hinge according to the plane

$$\begin{pmatrix} x_F \\ \\ y_F \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos\varphi_1 + l_{CF} \cdot \cos\varphi_3 \\ \\ l_{AC} \cdot \sin\varphi_1 + l_{CF} \cdot \sin\varphi_3 \end{pmatrix} \tag{24}$$

Differentiating the system of equations (24), we obtain:

$$\begin{pmatrix} \dot{x}_F \\ \\ \dot{y}_F \end{pmatrix} = \begin{pmatrix} -l_{AC}\omega_1 \sin\varphi_1 - l_{CF}\omega_3 \sin\varphi_3 \\ \\ l_{AC}\omega_1 \cos\varphi_1 + l_{CF}\omega_3 \cos\varphi_3 \end{pmatrix} \tag{25}$$

and the speed of rotation of point F :

$$\nu_F = \sqrt{l_{AC}^2\omega_1^2 + l_{CF}^2\omega_3^2 + 2l_{AC}\omega_1 l_{CF}\omega_3 \cos(\varphi_3 - \varphi_1)} \tag{26}$$

By differentiating equations (25) we obtain the projections of the accelerations of the point F on the x and y coordinate axes.

$$\begin{pmatrix} \ddot{x}_F \\ \\ \ddot{y}_F \end{pmatrix} = \begin{pmatrix} -l_{AC}\varepsilon_1 \sin\varphi_1 - l_{AC}\omega_1^2 \cos\varphi_1 - l_{CF}\varepsilon_3 \sin\varphi_3 - l_{CF}\omega_3^2 \cos\varphi_3 \\ \\ l_{AC}\varepsilon_1 \cos\varphi_1 - l_{AC}\omega_1^2 \sin\varphi_1 + l_{CF}\varepsilon_3 \cos\varphi_3 - l_{CF}\omega_3^2 \sin\varphi_3 \end{pmatrix} \tag{27}$$

Acceleration of point F

$$a_E = \sqrt{\ddot{x}_F^2 + \ddot{y}_F^2} \tag{28}$$

Coordinates of the G-hinge with the plane

$$\begin{pmatrix} x_G \\ \\ y_G \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos\varphi_1 + l_{CF} \cdot \cos\varphi_3 + l_{FG} \cdot \cos\varphi_4 \\ \\ l_{AC} \cdot \sin\varphi_1 + l_{CF} \cdot \sin\varphi_3 + l_{FG} \cdot \sin\varphi_4 \end{pmatrix} \tag{29}$$

By differentiating by time (29), we obtain the projections of the velocity of the point G on the x and y coordinate axes.

$$\begin{pmatrix} \dot{x}_G \\ \\ \dot{y}_G \end{pmatrix} = \begin{pmatrix} -l_{AC}\omega_1 \sin\varphi_1 - l_{CF}\omega_3 \sin\varphi_3 - l_{FG}\omega_4 \sin\varphi_4 \\ \\ l_{AC}\omega_1 \cos\varphi_1 + l_{CF}\omega_3 \cos\varphi_3 + l_{FG}\omega_4 \cos\varphi_4 \end{pmatrix} \tag{30}$$

and the speed of rotation of point G :

$$\nu_G = \sqrt{\dot{x}_G^2 + \dot{y}_G^2} \tag{31}$$

By differentiating equations (30) we obtain the projections of the accelerations of the point G on the x and y coordinate axes.

$$\begin{pmatrix} \ddot{x}_G \\ \ddot{y}_G \end{pmatrix} = \tag{32}$$

$$= \begin{pmatrix} -l_{AC}\varepsilon_1 \sin\varphi_1 - l_{AC}\omega_1^2 \cos\varphi_1 - l_{CF}\varepsilon_3 \sin\varphi_3 - l_{CF}\omega_3^2 \cos\varphi_3 - l_{FG}\varepsilon_4 \sin\varphi_4 - l_{FG}\omega_4^2 \cos\varphi_4 \\ l_{AC}\varepsilon_1 \cos\varphi_1 - l_{AC}\omega_1^2 \sin\varphi_1 + l_{CF}\varepsilon_3 \cos\varphi_3 - l_{CF}\omega_3^2 \sin\varphi_3 + l_{FG}\varepsilon_4 \cos\varphi_4 - l_{FG}\omega_4^2 \sin\varphi_4 \end{pmatrix}$$

Acceleration of point G

$$a_G = \sqrt{\ddot{x}_G^2 + \ddot{y}_G^2} \tag{33}$$

Convert the coordinates of the points in the plane found above to the coordinates in space:

$$\begin{pmatrix} X_C \\ Y_C \\ Z_C \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos\varphi_1 \cdot \cos\varphi_y \\ l_{AC} \cdot \sin\varphi_1 \\ -l_{AC} \cdot \cos\varphi_1 \cdot \sin\varphi_y \end{pmatrix} \tag{34}$$

Corresponding spatial coordinates of the C-hinge.

$$\begin{pmatrix} X_D \\ Y_D \\ Z_D \end{pmatrix} = \begin{pmatrix} l_{AD} \cdot \cos\varphi_1 \cdot \cos\varphi_y \\ l_{AD} \cdot \sin\varphi_1 \\ -l_{AD} \cdot \cos\varphi_1 \cdot \sin\varphi_y \end{pmatrix} \tag{35}$$

Corresponding coordinates of the D-hinge in space.

$$\begin{pmatrix} X_E \\ Y_E \\ Z_E \end{pmatrix} = \begin{pmatrix} l_{AE} \cdot \cos\varphi_1 \cdot \cos\varphi_y \\ l_{AE} \cdot \sin\varphi_1 \\ -l_{AE} \cdot \cos\varphi_1 \cdot \sin\varphi_y \end{pmatrix} \tag{36}$$

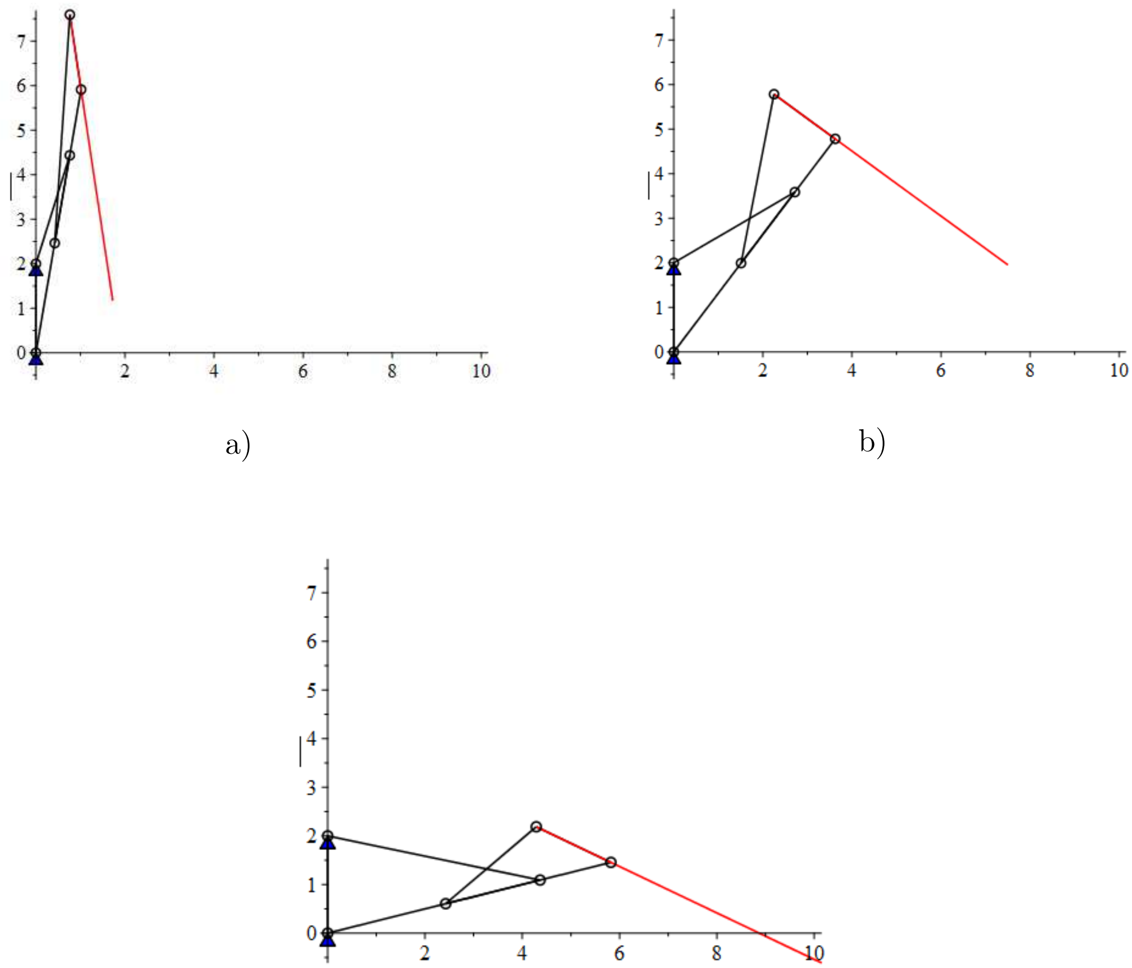
Corresponding spatial coordinates of the e-hinge.

$$\begin{pmatrix} X_F \\ Y_F \\ Z_F \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos\varphi_1 \cdot \cos\varphi_y + l_{CF} \cdot \cos\varphi_3 \cdot \cos\varphi_y \\ l_{AC} \cdot \sin\varphi_1 + l_{CF} \cdot \sin\varphi_3 \\ -l_{AC} \cdot \cos\varphi_1 \cdot \sin\varphi_y - l_{CF} \cdot \cos\varphi_3 \cdot \sin\varphi_y \end{pmatrix} \tag{37}$$

Corresponding coordinates of the F-hinge in space.

$$\begin{pmatrix} X_G \\ \\ Y_G \\ \\ Z_G \end{pmatrix} = \begin{pmatrix} l_{AC} \cdot \cos\varphi_1 \cdot \cos\varphi_y + l_{CF} \cdot \cos\varphi_3 \cdot \cos\varphi_y + l_{FG} \cdot \cos\varphi_4 \cdot \cos\varphi_y \\ \\ l_{AC} \cdot \sin\varphi_1 + l_{CF} \cdot \sin\varphi_3 + l_{FG} \cdot \sin\varphi_4 \\ \\ -l_{AC} \cdot \cos\varphi_1 \cdot \sin\varphi_y - l_{CF} \cdot \cos\varphi_3 \cdot \sin\varphi_y - l_{FG} \cdot \cos\varphi_4 \cdot \sin\varphi_y \end{pmatrix} \tag{38}$$

Corresponding spatial coordinates of the G-hinge.



a) b) c)

Figure 2: Position and trajectory of the power robot manipulator: a) initial position; b) position in plane motion; c) the final state in plane motion.

3 Results and discussion

Obtaining numerical values of the direct calculation of kinematics is carried out using the program Maple.

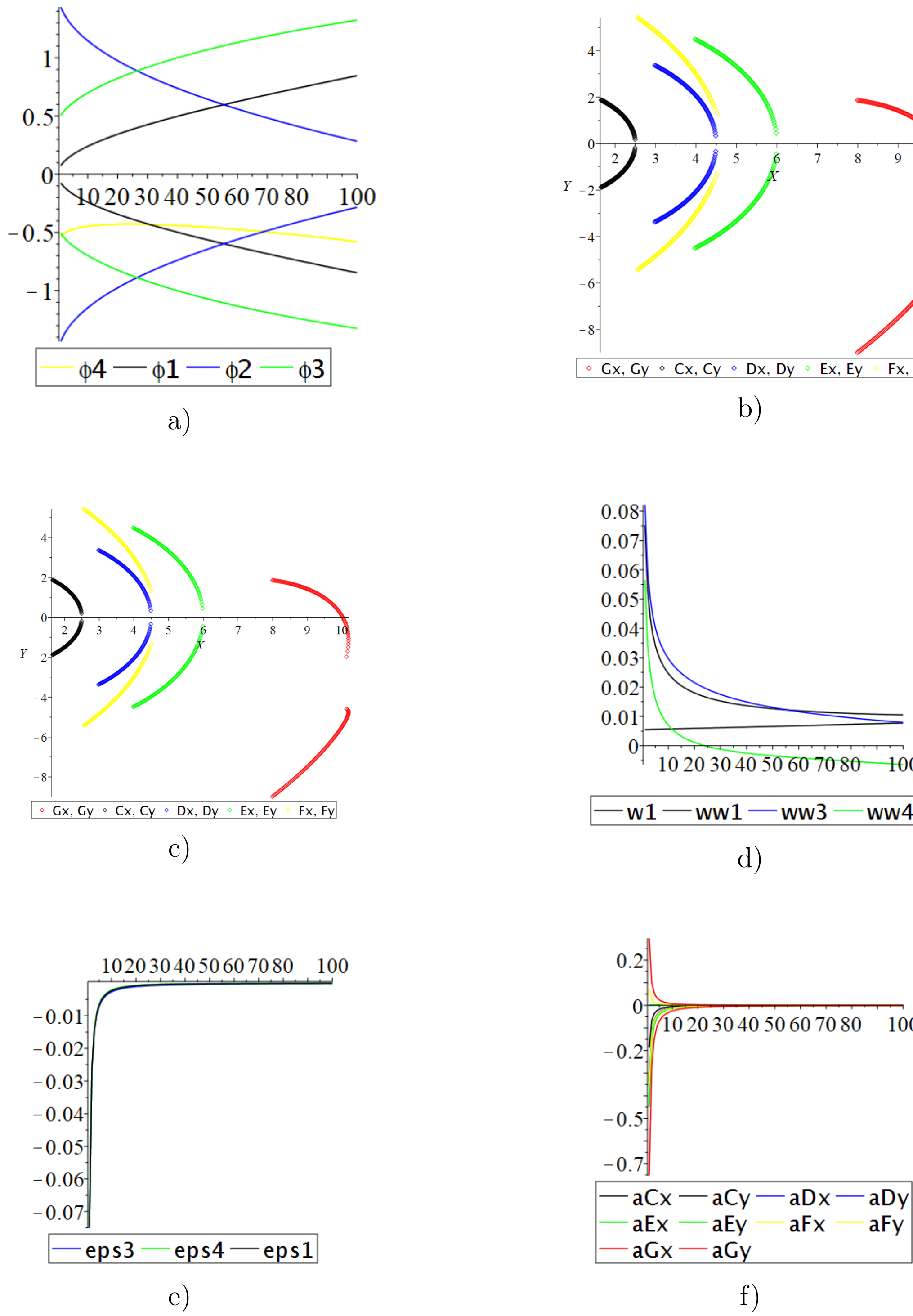


Figure 3: a) changes in the angles of the power robot manipulator; b) changes in the coordinates of the joints of the power robot manipulator; c) changes in the speed of the joints of the power robot manipulator; d) changes in the angular velocities of the joints of the power robot manipulator; e) changes in the angular accelerations of the joints of the power robot manipulator; f) changes in the angular accelerations of the joints of the power robot manipulator.

4 Conclusion

This paper considers a hydraulically driven drilling robot with four degrees of freedom. The use of mechanisms of variable structures significantly increases the reliability of vibration shocks, their design is simple and does not require imported materials and components. This is especially important for machines operating in difficult mountain conditions. Under the above operating conditions, semi-automatic or fully computer-controlled machines can work successfully and efficiently. To do this, it is important to understand the kinematics of this machine. therefore, the article described the sequence of actions required to solve the direct problem of kinematics directed at a drilling robot with four degrees of freedom. Based on this evidence, we solved the direct kinematics of the drilling robot using the geometric method. Numerical values of the direct calculation of kinematics were obtained using the program Maple.

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