MACHINE SCIENCE

ISSN: 2227-6912
E-ISSN: 2790-0479

2023, № 1 Pages 61 – 67

KINEMATIC CALCULATION OF VARIABLE CURVATURE FIST MECHANISM WITH CONVEX PROFILE

Ahmad IMANOV

Department of Mechatronics and Machine Design of Azerbaijan Technical University, Baku, Azerbaijan

E-mail: ehmed.imanov@aztu.edu.az

Abstract: In order to take into account more boundary conditions, a new modified equation was obtained to establish the profile of the fist by adding a constant to the equation obtained from the solution of the differential equation of curvature (i.e., $k < 0$ - convex profile surface as a special case). Based on this equation, the expression defining the movement of the pusher based on the rotation angle of the fist was deduced. The kinematic report of the punching mechanism was performed on the basis of a modified formula. During the kinematic calculations, it was found that there are no jumps in the displacement, velocity and acceleration diagrams of the pusher, that is, the mechanism works smoothly. In order to verify that the curvature takes a negative value along the profile, the equation of the curvature was deduced, its graph was plotted and its accuracy was confirmed.

Keywords: *profile, punch, flat pusher, speed, momentum, punch mechanism, impact, radius of curvature.*

Introduction. The task of the punch is to convert the rotational movement of the shaft into the forward movement of the pusher. The profile of the fist is formed by a circle, a straight line and various curved lines that meet each other [1]. Figure 1 shows a convex profile gas distribution mechanism that actuates the valve of an internal combustion engine with a flat pusher.

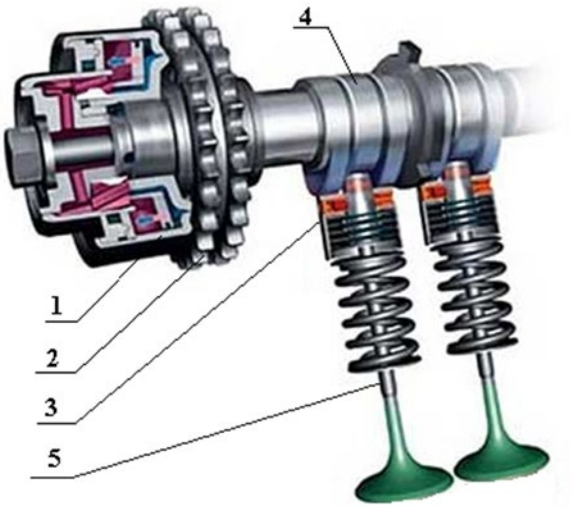

Figure 1. Gas distribution mechanism:
1 - clutch; 2 - wheel; 3 - thruster; 4 - punched shaft; 5 - valve.

The works of many authors are devoted to the modeling, design, kinematic and dynamic analysis of punching mechanisms. For example, T.A. Polyakova (with co-authors) carried out a kinematic report of the camshaft punch of the gas distribution mechanism of diesel engines using the graphical method, using the MathCAD program. As a result, they constructed displacement, velocity and acceleration diagrams of the thruster [2]. H.D.Desai and V.K.Patel performed computer-aided kinematic and dynamic analysis of the punch and pusher to determine the critical angular velocities of each section [3]. R.D.V. Prasad (with co-authors) performed a kinematic and dynamic analysis for the modification of a flat pusher punch mechanism. The aim of the study was to improve the performance of the mechanism by reducing the contact stresses in the meeting areas. The authors defined expressions for displacement, speed and acceleration of the pusher and punch based on geometrical parameters [4]. M. Mali (with co-authors) used point contact, replacing the flat pusher with a convex pusher, in order to increase the efficiency of the mechanism in four-stroke internal combustion engines, to reduce the friction force [5]. I.A. Khalilov (with co-author) kinematic analysis of the punched mechanism built on the basis of the curvature quality indicator, in his scientific article, in solving the design and optimization issues of the punched mechanism profiled on the basis of the curvature, which is one of the geometric criteria of quality, analytical with the application of the MathCAD program, and with the application of the SolidWORKS program, the most promising for today considered, kinematic analysis based on computer numerical experiment was given [6].

Modern CNC (Computer Numerical Control) machines, which perform profiling with high precision, are widely used in punch manufacturing technologies. It is very important to have accurate coordinates for processing the profile on CNC machines. Since the known graphical methods for determining coordinates [7] are rather imprecise, profiling is mainly built with analytically obtained curves.

Analytical calculation of the fist. At high speeds of the shaft, the smooth change of curvature along the profile ensures the absence of shocks in the punch mechanism. The only geometrical parameter that affects the contact stress in punched mechanisms intended to work under a large load is the introduced curvature radius [8]. The monotonous change of the radius of curvature without a jump in the graph during the departure and approach phases allows for the absence of the first type of shocks in those phases.

The profile of the punch in mechanisms with a flat pusher punch is made in a convex shape. To provide convexity to all points of the profile, its curvature factor $k < 0$ condition must be met. In the presented article, the differential equation of curvature (1) for constructing a profile with a variable curvature coefficient with a convex profile, in a special case, the equation of a convex profile curve (2) was obtained [9].

$$k(x) = \frac{\dfrac{d^2y}{dx^2}}{\sqrt{\left(1+\left(\dfrac{dy}{dx}\right)^2\right)^3}}, \tag{1}$$

The equation of the curve in (1) is not clearly defined. With the coefficient of curvature being negative, that is, convex, the equation of the profile line can be obtained by using the trigonometric equation (2) provided that certain criteria are met [10-12]:

$$k(x) = -a \cdot \sin\left(p \cdot x\right), \tag{2}$$

where $k(x)$ - function of curvature; y is the equation of the profile curve.

Equation (2) can be solved taking into account (1) and the following expression can be obtained

$$y(x) = \frac{1}{p}\ell n\left(\sin\left(p \cdot x\right) + \sqrt{\left(\frac{p}{a}\right)^2 - \cos^2\left(p \cdot x\right)}\right) + C, \tag{3}$$

where C is an integral constant.

The presence of three constants (a, p, C) in expression (3) complicates the use of four boundary conditions. That is, the report is redone by changing some input parameters to satisfy the fourth boundary condition. This increases the number of iterations and necessitates undesired corrections to some of the input parameters. However, this problem can be solved by adding a new constant to expression (3). By adding the constant K to expression (3), all basic boundary conditions can be taken into account. These are: starting (x_1, y_1), ending (x_2, y_2) points and tangents at these points (t_1 and t_2) (Figure 2).

$$y(x) = \frac{K}{p}\ell n\left(\sin\left(p \cdot x\right) + \sqrt{\left(\frac{p}{a}\right)^2 - \cos^2\left(p \cdot x\right)}\right) + C, \tag{4}$$

Expression (4) is called the modified equation of (3).

Input parameters are set to perform kinematic calculations using MathCAD software. These parameters include: $r_0 := 20$, $r_1 := 20$, $\varphi_1 := 10^o$, $\varphi_2 := 10^o$, $a_0 := |o_0 o_1| = 28$, $x_1 := r_0 \cdot (1 - \cos(\varphi_1 \cdot \deg))$ -(Figure 2), $x_2 := \dfrac{-r_1 \cdot \tan(\varphi_2 \cdot \deg)}{\sqrt{1 + \tan(\varphi_2 \cdot \deg)^2}} + r_0$, $y_1 := r_0 \cdot \sin(\varphi_1 \cdot \deg)$, $y_2 := \sqrt{r_1^2 - (x_2 - r_0)^2} + a_0$ - y_2 is obtained

To find the coefficients of p, a, C, K in (4), the following system of equations is jointly solved in Mathcad, subject to the aforementioned boundary conditions.

Given

$$\frac{K}{p}\ell n\left(\sin\left(p \cdot x_1\right) + \sqrt{\left(\frac{p}{a}\right)^2 - \cos^2\left(p \cdot x_1\right)}\right) + C = y_1$$

$$\frac{K}{p}\ell n\left(\sin\left(p \cdot x_2\right) + \sqrt{\left(\frac{p}{a}\right)^2 - \cos^2\left(p \cdot x_2\right)}\right) + C = y_2$$

$$\frac{dy(x_1)}{dx} = \tan(\varphi_1 \cdot \deg)$$

$$\frac{dy(x_2)}{dx} = \cot(\varphi_2 \cdot \deg)$$

$$\begin{pmatrix} p \\ a \\ C \\ K \end{pmatrix} = Find(p, a, C, K)$$

The following formulas are used to convert from the Cartesian coordinate system to the polar coordinate system (Figure 3). Polar angle $\varphi(x) := a\tan\left(\dfrac{y(x)}{r_0 - x}\right)$ and polar radius $|o_0 A| := \sqrt{y(x)^2 + (r0 - x)^2}$ are determined by expressions. Figure 3 is used to derive the thruster displacement equation at interval $|x_1, x_2|$. From the figure, it is the angle formed by the tangent at point $\varphi_t(x) := a\tan\left(\frac{dy(x)}{dx}\right)$ - x, y with the axis of x. In interval $(x_2, r_0]$, equation $y(x)$ is replaced by $y_{r1}(x) := \sqrt{r_1^2 - (x - r_0)^2} + a_0$, and $\varphi_t(x)$ by $\varphi_{r1}(x) := a\tan\left(\frac{dy_{r1}(x)}{dx}\right)$ for a circle with a radius of r_1.

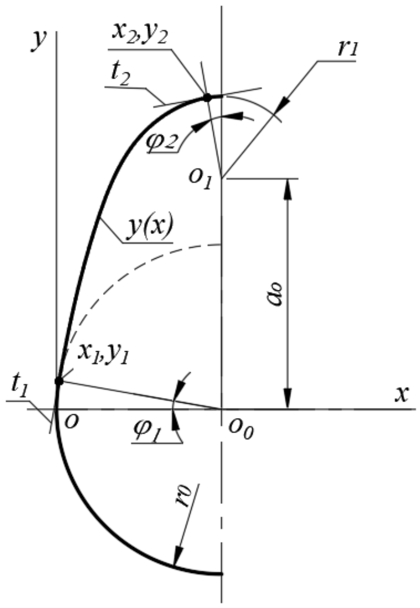

Figure 2. Graphical representation of boundary conditions.

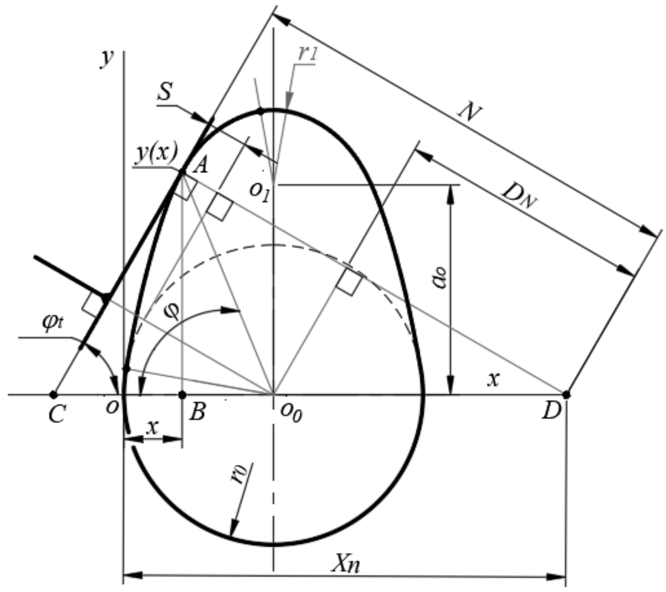

Figure 3. Profile of the fist

As can be seen from Figure 2 and Figure 3, the displacement of the thruster is denoted by S and is found as follows.

$$S(x) := \begin{vmatrix} N(x) - D_N(x) - r_0 \quad if \quad x \le r_0 \\ \dfrac{y_{r1}(x)}{\cos(\varphi_{r1}(x))} - r_0 \quad otherwise \end{vmatrix} \tag{5}$$

where from Figure 3, $N(x) = \dfrac{y(x)}{\sin\left(\dfrac{\pi}{2} - \varphi_t(x)\right)}$, $D_N(x) = \left(\dfrac{y(x)}{\tan\left(\dfrac{\pi}{2} - \varphi_t(x)\right)} + x - r_0\right) \cdot \cos\left(\dfrac{\pi}{2} - \varphi_t(x)\right)$.

The movement of the pusher is carried out by the equation (5) in the interval $|x_1, x_2|$, and the equation of the circle with the center point o_1 and the radius r_1 in the interval $(x_2, r_0]$ is used.

Figure 4 shows the dependence diagram of the thruster rotation angle obtained on the basis of (5). The maximum value of the displacement corresponds to the maximum of a circle with a radius of r_1 at a turning angle of 90^0 (18 *mm*), as intended. As can be seen from the speed diagram, it changes smoothly, which means that there are no shocks of the first type (Figure 5). A sharp increase in the speed of the pusher during the take-off phase is an indication of rapid opening of the valves. There are no jumps in the momentum diagram, it changes smoothly, and this is the main condition for the absence of the second type of shocks (Figure 5).

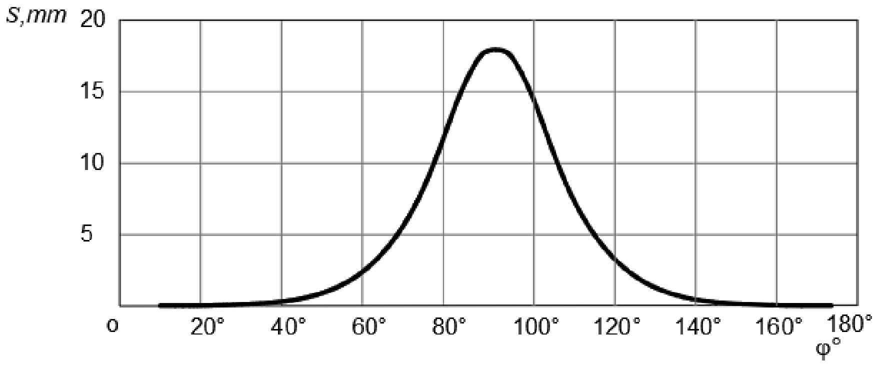

Figure 4. Diagram of dependence of thruster displacement on rotation angle

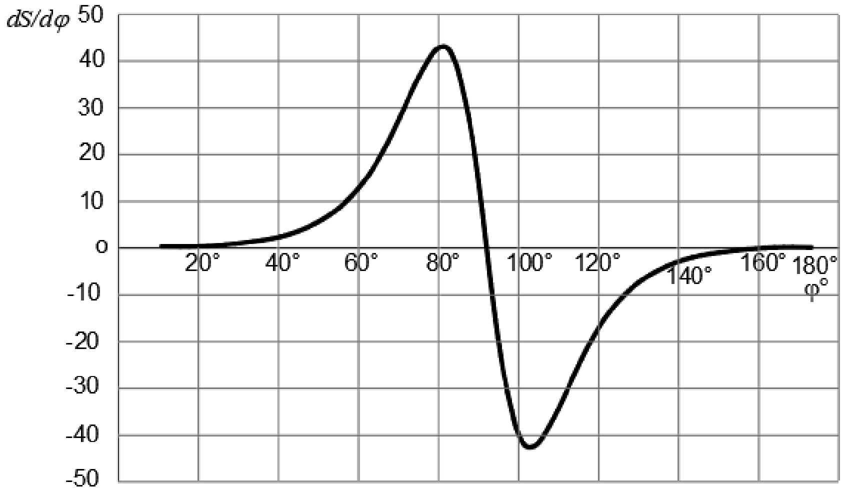

Figure 5. Diagram of the dependence of the speed analog of the thruster on the angle of rotation

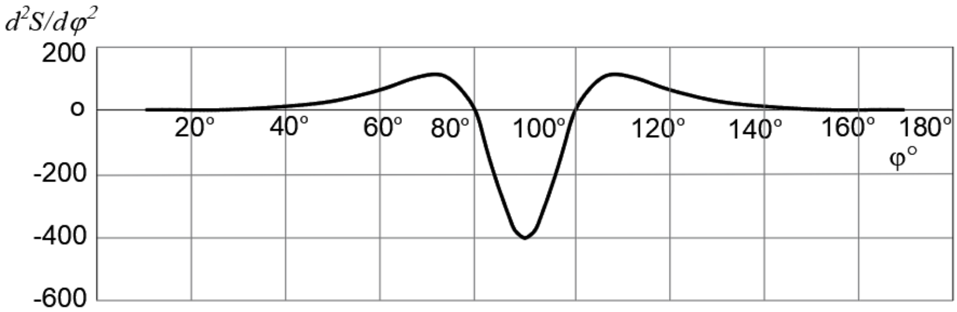

Figure 6. Diagram of dependence of the thruster's momentum analogue on the angle of rotation

As we mentioned, the value of the curvature coefficient is negative throughout the profile, so the profile should theoretically be convex. This boundary condition was used in the derivation of equation (3). However, expression (4) was used to draw the profile curve by adding K correction factors to equation (3) to account for the basic boundary conditions. Equation (4) is a modified version of (3). The curvature coefficient of the profile curve drawn by (4) is determined by expression (6).

$$k(x) := \left(\frac{p}{a}\right)^2 \cdot K \frac{-p \cdot \sin(p \cdot x)}{\left[\left(\frac{p}{a}\right)^2 + \cos(p \cdot x)^2 \cdot \left(K^2 - 1\right)\right]^{\frac{3}{2}}} \tag{6}$$

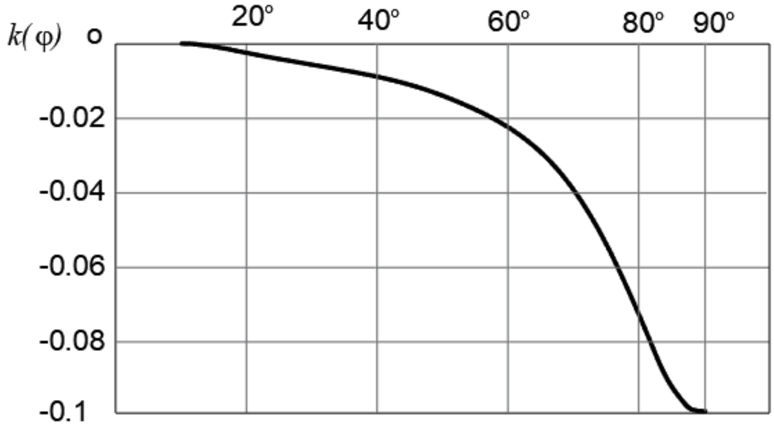

Figure 7. The curvature coefficient of the profile line

As can be seen in Figure 7, the value of the curvature coefficient is negative along the entire profile line. This is the main condition for the profile to be prominent.

Since the pusher is plane and located in the position touching the fist, the pressure angle is zero.

Conculations.

1. The differential equation of curvature for a convex profile, for a special case, was solved and the obtained expression was modified to take into account the main boundary conditions, and a new equation was obtained.

2. The thruster's displacement equation was deduced and the speed and acceleration expressions were obtained by differentiating it. Based on the received statements, the punch mechanism was kinematically calculated, and displacement, speed, and acceleration graphs of the pusher were constructed for visual display.

3. A new approach for the kinematic calculation of a punch mechanism with a convex profile and a variable radius of curvature is given.

4. The curvature formula of the curvature base, which is a criterion of geometric quality, has been derived.

5. The presented method can be used in the creation of special software for kinematic calculation and automatic design of punched mechanisms with a convex profile.

REFERENCES

[1]. Artobolevsky, I.I. *Theory of mechanisms and machines*. Moskow, Nauka, 1988, 640 p (in Russian).

[2]. Polyakova, T.A., Makushev, Yu.P., Volkova, L.Yu., Ryndin, V. V. *Kinematic calculation of convex profile cams using the Mathcad program.* Omsk Scientific Bulletin, 2021, No. 5 (179), pp. 34–40.

[3]. Patel, H.D.P.V. *Computer aided kinematic and dynamic analysis of cam and follower.* In Proceedings of the World Congress on Engineering, 2010, Vol. 2, (in Russian).

[4]. Prasad, R.D.V., Satyanarayana, K., Maheswara, Ch. et al. *Analysis of Cam and Follower Mechanism to Reduce Jerk and Induced Stresses.* Journal of Recent Trends in Mechanics, 2020, Vol. 5 (3), pp. 8–17.

[5]. Mali, M., Maskar, P., Gawande, S., and Bagi, J. *Design Optimization of Cam & Follower Mechanism of an Internal Combustion Engine for Improving the Engine Efficiency.* Modern Mechanical Engineering, 2012, Vol. 2, No. 3, pp. 114-119.

[6]. Khalilov, I.A., Imanov, A.S. *Modeling of the cam mechanism taking into account quality criteria.* Bulletin of Kherson Technical University, 2017, 4(63), pp. 126 – 134 (in Russian).

[7]. Pylaev, B.V. *Method for profiling flat cams.* Moscow State Agro engineering University named after V.P. Goryachkina, 2010, pp. 78-81 (in Russian).

[8]. Birger, I.A., Shorr, B.F., Iosilevich, G.B. *Calculation of the strength of machine parts.* Moskow, 1979, 702 p (in Russian).

[9]. Imanov, A.S., Khalilov, I.A., Aliyev,A.G. *New approach to calculation of transition curves on curved roads.* Proceedings of the International Conference on Problems of Logistics, Management and Operation in the East-West Transport Corridor (PLMO), Baku, Azerbaijan, October 27-29, 2021.

[10]. Imanov, A.S., Khalilov I.A. *Research of development processes in three-dimensional gas Flows in turbomachine.* "Machine-building and Energy: New Concepts and Technologies" International Scientific-practical Conference materials, AzTU, Baku, Azerbaijan, December 2-3, 2021.

[11]. Imanov, A.S., Khalilov, I.A. *Blade profile optimization built based on the differential curvature equation.* Proceedings of the 8th International Conference on Control and Optimization with industrial applications. Baku, Azerbaijan. 24-26 August, Vol. 2, 2022, pp. 240-242.

[12]. Imanov, A.S., Khalilov, I.A. *3D modeling and analysis of gas flow in the interblade channel.* SOCAR Proceedings, 2022, Special Issue 1, pp. 1-5.

Received: 14.09.2022
Accepted: 24.01.2023