**TRANSPORT TECHNOLOGIES**

**Vol. 5, No. 2, 2024**

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https://doi.org/10.23939/tt2024.02.075

# JUSTIFYING THE STRUCTURE OF THE IMPROVED MECHANISM FOR MANUAL CONTROL OF MOTOR VEHICLES' PEDALS

***Summary.*** *Due to the challenging military situation in Ukraine, the demand for tailored and flexible pedal control systems for individuals with physical disabilities is especially important. Standard pedal configurations often fail to meet the specific needs of drivers with limited mobility, making vehicle operation both difficult and potentially unsafe. The development of specialized manual control devices, such as hand-operated pedals or adjustable foot controls, is crucial for ensuring that these drivers can manage their vehicles with accuracy and safety. Such innovations not only improve accessibility but also foster greater autonomy and inclusion, empowering disabled drivers to navigate the roads with confidence and ease.*

*This article aims to review existing prototypes of manual control mechanisms for vehicle pedals and to develop an improved device that enables simultaneous control of three pedals – accelerator, brake, and clutch – with one hand. As a result of a patent review of several existing prototypes of control mechanisms, it was concluded that the vast majority of them provide control for only two pedals – the accelerator and brake. This means they can only be used in motor vehicles with automatic transmissions or electric cars. Only a few mechanisms were designed to control three pedals, but they required using both the driver's hands, directly affecting driving safety. Therefore, improving existing designs of the mechanisms for controlling three pedals by transferring all control functions to one hand of a driver remains relevant.*

*The research methodology involves the use of classical methods from the theory of mechanisms and machines to conduct the structural synthesis of an improved multi-link hinge-lever mechanism and its kinematic analysis, aimed at determining the main parameters of pedals' movements in a vehicle under various control inputs from the driver's hand. The results obtained can be utilized by researchers and engineers to enhance manual control mechanisms for vehicle pedals and in the practical implementation processes. The prospects for future research on this topic are in developing an experimental prototype of the control mechanism and its testing and adjustment for different vehicle modifications to improve running smoothness and driving comfort and safety.*

***Key words:*** *motor vehicle control, driving comfort, driving safety, running smoothness, structural synthesis, kinematic analysis, motion parameters.*

## 1. INTRODUCTION

The manual control of vehicle pedals is a critical component of the automotive operation, serving as the primary interface between the driver and the vehicle's acceleration, deceleration, and gear shifting in the case of manual transmissions. Pedals translate human intent into mechanical action, enabling precise control over speed and braking – functions essential for safe and efficient driving. Despite significant advancements in automotive

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technology, including the emergence of autonomous vehicles and advanced driver-assistance systems (ADAS), most vehicles still rely on manual pedal control. Understanding the mechanisms behind this control is crucial for improving vehicle design, enhancing driver ergonomics, and reducing accidents related to pedal misuse.

The mechanics of pedal operation involve a complex interplay between mechanical linkages, electronic systems, and human factors. Traditional mechanical systems have evolved into sophisticated assemblies incorporating sensors, actuators, and feedback mechanisms. Innovations such as drive-by-wire throttle control and anti-lock braking systems (ABS) have enhanced vehicle responsiveness and safety but introduced new challenges related to system complexity and reliability. These technological advancements necessitate a deeper exploration of how manual input is translated into vehicular action.

Human interaction with vehicle pedals encompasses physiological and cognitive factors, including muscle memory, reaction time, and ergonomic considerations. Issues such as driver fatigue, improper seating position, and pedal placement can lead to errors with severe consequences. Pedal misapplication incidents, although relatively rare, highlight the need for improved design and a better understanding of human-machine interaction. Studies indicate that ergonomic enhancements and intuitive pedal layouts can significantly reduce the likelihood of such errors.

Moreover, for individuals with physical disabilities, the need for customized and adaptable pedal control mechanisms becomes even more critical. Standard pedal designs may not accommodate the unique physical requirements of disabled drivers, making driving both challenging and unsafe. Developing specialized manual control systems, such as hand-operated pedals or adjustable foot controls, is essential to ensure these individuals can operate vehicles with the same level of precision and safety. These advancements not only enhance accessibility but also promote greater independence and inclusivity for disabled drivers, enabling them to navigate roads with confidence and security.

## 2. RESEARCH PURPOSE STATEMENT

This paper aims to examine the manual control mechanisms of vehicle pedals by analyzing the mechanical systems involved and substantiating the enhanced structure of the multi-link hinge-lever mechanism for manual control of three pedals (accelerator, brake, and clutch). Additionally, the research will contain the kinematic analysis of the proposed mechanism, aimed at determining the main parameters of pedal movement in a vehicle under various control inputs from the driver's hand. The following research tasks are accomplished to reach the prescribed goal:

– to carry out a comprehensive analysis of recent patents related to the mechanisms and systems for manual control of the motor vehicle pedals;
– to carry out the structural synthesis of an improved multi-link hinge-lever mechanism for manual control of three pedals (accelerator, brake, and clutch);
– to carry out the kinematic analysis of the proposed mechanism and to study the main motion characteristics of the pedals under various control inputs from the driver's hand;
– to draw conclusions about the possibilities of practical implementation of the proposed mechanism and to outline the prospects of further research on this subject.

## 3. REVIEW OF RECENT PATENTS

Numerous patents are dedicated to the designs and techniques of manual control of the motor vehicles' pedals. The first designs date back to the early 20$^{th}$ century. Let us consider the most recent patents presented in [1]–[17]. One of the simplest manual control mechanisms is presented in [1]. A passenger-side driving instructor brake controller incorporates a telescopic shaft with a first and second end. A brake lever connector, attached to the first end of the shaft, is designed to secure a brake lever located within the driver-side front floorboard area of the vehicle. A tubular main body bent near its center is configured to adjustably accommodate the second end of the telescopic shaft. Locking hardware secures the shaft in a fixed position within the main body, allowing the main body to traverse over the vehicle's central console and extend into the passenger compartment. In [2], a remote braking system is designed to enable passengers to apply vehicle brakes. It comprises a roller unit attached to the vehicle’s floorboard. This roller unit is aligned with the vehicle’s brake pedal. A handle, positioned within the vehicle and accessible to passengers, is connected to the brake pedal via a cable. When the handle is moved into a braking position, the cable pulls the brake pedal downward, allowing the passenger to activate the vehicle’s brakes remotely. Patent [3] outlines a manually operated device designed to activate vehicle acceleration and brake pedals. This device incorporates a brake bar with a first end equipped to connect to the vehicle’s brake pedal. The second end of the brake bar is joined to a handlebar, providing transverse support. The braking mechanism proposed in [4] incorporates a support tube that is pivotally connected near the steering column. A brake tube connects the control tube to the brake pedal, activating and deactivating the brake pedal.

The innovation presented in [5] introduces the manual mechanism for the pedal control designed for individuals with physical impairments, specifically catering to those with lower limb disabilities who manually operate the brakes and accelerator while seated in the driver’s seat. A single-link driving assistance system designed in [6] for individuals with disabilities incorporates a control bar that forms a hinged connection with the steering column, creating a rotational center for upward and downward steering wheel movements. A pedal operation link, consisting of an inner tube attached to the control bar, transmits downward force to the brake pedal. An outer tube encases the inner tube, moving with it during downward operations to activate the brake pedal. The invention presented in [7] introduces a driver assistance device designed for individuals with leg impairments, allowing them to operate the brake and accelerator pedals using a single hand. This device enables disabled drivers to maintain a desired brake and accelerator pedal position even when their hand is temporarily removed. The device incorporates a connecting bar attached to one side of the brake and accelerator pedals, a support shaft mounted on the steering column cover, a rotating member within the support shaft, an operating bar connected to both sides of the rotating member, and the other end of the connecting bar, and an operating lever extending laterally from the rotating member to achieve this. The combined brake and accelerator pedal assembly proposed in [8] enhances two-pedal vehicle control. The accelerator pedal is mechanically linked to an engine control lever that can be engaged or disengaged. Pressing the accelerator engages the lever, accelerating the vehicle, while releasing it disengages the lever, preventing acceleration. A supplementary accelerator pedal disengagement device, connected to both the brake and accelerator pedals, automatically disengages the engine control lever when the brake pedal is pressed. This mechanism prevents accidental acceleration when both pedals are pressed simultaneously.

One of the modern hand-operated systems for controlling the vehicle’s brake and accelerator pedals is presented in [9, 10]. It utilizes a planetary gear train consisting of a sun gear, a ring gear, and planetary gears that mesh with both. The planetary gears are attached to a carrier. A carrier flange connected to the carrier rotates with it. A sun gear flange engages the sun gear, and rotating the sun gear flange turns the sun gear. A lever is positioned near the sun gear flange. An accelerator actuation assembly, linked to the lever, connects to the accelerator pedal. A brake actuation assembly, attached to the carrier flange, connects to the brake pedal. Patent [11] describes a driving assistance device designed for one-handed operation of the accelerator and brake pedals. This device features a brake control system with an operating lever equipped with a gripping arm at the top and an acceleration roller at the bottom. The top of the lever is mounted on a rotatable support plate. A braking roller contacts the operating lever's lower part, which is connected to a braking link with a support plate attachment and a brake wire. A pressing arm attached to the support plate has a brake wire connection and a roller to activate the brake arm. The acceleration control system includes an L-shaped acceleration link that contacts the roller on the operating lever. The link’s midsection is mounted on the rotatable support plate, and its upper end connects to an acceleration wire. An acceleration arm, attached to a support shaft, also connects to the wire.

The invention presented in [12] introduces a manual operating device for a motor vehicle’s accelerator and brake pedals, designed to be mounted near the vehicle’s seat attachment point. The device features a base part board with a first pivot axis and a control panel mounted on the board’s upper portion with a second pivot axis. A first lever is fixed to the control panel, while a double lever with a first and second leg is pivotally mounted on the base part around the first pivot axis. A tie rod connects the first lever to the first leg of the double lever. The second leg of the double lever is connected to a first actuating rod that can be linked to the accelerator pedal. Additionally, with a central articulation point, the board connects to a second actuating rod that can be linked to the brake pedal. The board is perpendicular to the pivot axes plane, with an angled upper portion, and the tie rod is also angled. The invention proposed in [13] focuses on driving assistance for individuals with disabilities, specifically a device for manually controlling a motor vehicle's accelerator and brake pedals. The oscillating lever's support structure is designed to be fixed to the vehicle's floor, with at least one attachment point near the vehicle's side. Ideally, the support structure would have two attachment points near the side, positioned horizontally and vertically. Additionally, the support structure can be attached to one of the driving seat's longitudinal sliding guides. The first lever is a rocker arm connected to the support structure, with an upper part attached to the accelerator pedal via a strut and a lower part equipped with a roller that makes contact with the elbow-shaped lower portion of the oscillating lever.

The handheld device in [14] controls a vehicle's brake and accelerator pedals. It includes a brake linkage connected to the brake pedal, a gas pedal linked to the throttle linkage, a rotatable handlebar mounted on a base, a connecting element joining the brake linkage to the handlebar, a connecting element joining the gas linkage to the base, and a handle on the handlebar. Notably, at least one connecting element is a lever mechanism comprising two levers articulated on the handlebar and base, respectively. These levers can be detached and reconnected to pivot the lever, allowing the handheld terminal to transition from working to resting. The invention [15] introduces a control device for manually driving automobiles. The device includes a mounting body, a brake push rod, and an accelerator push rod. The mounting body is placed on the vehicle's floor, with one end of the brake push rod connected to the body via a first height adjustment block. A brake clamp attaches the other end of the brake push rod to the brake pedal. Similarly, the accelerator push rod connects to the mounting body through a second height adjustment block, and an accelerator clamp attaches the other end to the accelerator pedal. The brake and accelerator push rods are connected to the mounting body using the height adjustment blocks, allowing for adjustable height. The push rods have different heights, resulting in varying sensitivity to the brake and accelerator pedals. It enables drivers to customize control sensitivity to their driving preferences, enhancing driving comfort for individuals with disabilities.

The invention [16] introduces a manual control device for operating a vehicle's accelerator and brake systems. The device includes a manual brake assembly, a button push rod assembly, and a manual accelerator assembly. The manual brake assembly comprises a brake lever fixing upright plate, a brake lever fixing frame, brake pedal fixing parts, and a brake push rod component. The button push rod assembly consists of a button-fixing frame. The manual accelerator assembly includes an accelerator handle plate, an accelerator barrier, an accelerator push rod component, and an accelerator pedal fixing part. Additionally, the device may include a seat-fixing assembly. The manual brake assembly can further include a brake latch and a push rod positioning block. The button push rod assembly may have a button push rod positioning ring, a button elastic component, and a button push rod check block. The manual accelerator assembly may also include an accelerator handle head. This manual control device is designed for ease of use and installation. Modifying an existing vehicle's accelerator and brake pedals and integrating them with the device can accommodate the driving needs of individuals with specific requirements. The device's simplicity and effectiveness make it suitable for widespread adoption and application. The invention [17] introduces a vehicle driving device that integrates brake and acceleration functions into a single bar. A lever, rotating a fixed angle front-to-back around a vehicle-mounted axis, controls acceleration, neutral, and brake positions. Moving the lever to the acceleration position opens the engine throttle, accelerating the vehicle. Shifting the lever to the brake position activates the brake by pressing the brake booster's booster bar. A hand brake mechanism provides a stopping function. Guides on the lever's left and right sides prevent lateral movement, while a hand brake fixing mechanism maintains the hand brake in the engaged position. Cruise control functionality allows the lever to remain in the acceleration position while maintaining a constant speed. This hand-operated lever operates independently of the existing brake and accelerator pedals, offering drivers the flexibility to choose between hand-operated or foot-operated driving, enhancing overall driver convenience.

As a result of the review of several existing prototypes of control mechanisms, particularly those presented in [1]–[16], it may be concluded that the vast majority of them provide control for only two pedals – the accelerator and brake. This means they can only be used in motor vehicles with automatic transmissions or electric cars. Only a few mechanisms were designed to control three pedals, but they required using both the driver's hands directly affecting driving safety. Therefore, improving existing designs of the mechanisms for controlling three pedals by transferring all control functions to one hand of a driver remains relevant.

## 4. STRUCTURAL SYNTHESIS AND KINEMATIC ANALYSIS OF THE IMPROVED MECHANISM FOR MANUAL CONTROL OF THREE PEDALS OF A MOTOR VEHICLE

In the process of creating any mechanism, one of the most important primary tasks is its structural synthesis [18]–[20], which involves selecting the structural scheme of the mechanism that has the required number of degrees of freedom, the number and type of links and kinematic pairs, ensuring the necessary movements of the links and their mutual arrangement. This synthesis stage is carried out based on a review of numerous patents related to devices capable of performing the specified functions, i.e., dedicated to mechanisms for manual control of vehicles' pedals [1]–17].

In our case, it is necessary for the mechanism to have two degrees of freedom: one – for controlling the accelerator and clutch pedals and the other – for controlling the brake pedal. As for the number of links, it should be minimized to simplify the mechanism's design and provide maximum reliability. Among the kinematic pairs, the major attention should be focused on pairs of classes 3 to 5. Based on the patent review and a series of draft sketches, our improved version of the mechanism's structure for the manual control of three vehicle's pedals was synthesized, as shown in Fig. 1. The proposed mechanism consists of eight movable links ($B_2O_1B_4$, $B_3C$, $B_2A_2$, $B_3A_3$, $B_4A_4$, $O_2A_2$, $O_3A_3$, $O_4A_4$), i.e., $n = 8$, and five single-movement kinematic pairs of the fifth class – the slider $B_3$ and four cylindrical joints ($O_1$, $O_2$, $O_3$, $O_4$), i.e., $p_5 = 5$, as well as six kinematic pairs of the third class – spherical joints $B_2$, $B_3$, $B_4$, $A_2$, $A_3$, $A_4$, i.e., $p_3 = 6$. The considered mechanism does not contain any kinematic pairs of the fourth, second, and first class, therefore, $p_4 = p_2 = p_1 = 0$. Let us determine the number of degrees of freedom of the mechanism using the following formula [20]:

$$W = 6\cdot n - 5\cdot p_5 - 4\cdot p_4 - 3\cdot p_3 - 2\cdot p_2 - p_1 = 6\cdot 8 - 5\cdot 5 - 4\cdot 0 - 3\cdot 6 - 2\cdot 0 - 0 = 5. \quad (1)$$

At first glance, it may seem that the proposed mechanism has five degrees of freedom, but in reality, three of them are due to the use of spherical joints in the connections of links $B_2A_2$, $B_3A_3$, and $B_4A_4$, which allow these links to rotate around their longitudinal axes. Thus, the angular positions $\varphi_2$, $\varphi_3$, and $\varphi_4$ of the motor vehicle's pedals (links $O_2A_2$, $O_3A_3$, $O_4A_4$) are uniquely determined by the angle $\varphi_1$ of the handle $C$ inclination and the distance $l_{O_1B_3}$ between the joints $O_1$ and $B_3$.

Considering the controllable parameters $\varphi_1$ and $l_{O_1B_3}$ as the generalized coordinates, let us carry out the kinematic analysis of the synthesized mechanism. Thus, let us deduce the equations of motion of the corresponding kinematic pairs located at the pushing rod of the studied manual control mechanism, expressed as functional dependencies on the considered generalized coordinates (see Fig. 1):

– spherical joint $B_2$:

$$x_{B_2} = x_{O_1} + l_{O_1B_2}\cdot\sin\varphi_1, \qquad y_{B_2} = y_{O_1} + l_{O_1B_2}\cdot\cos\varphi_1, \qquad z_{B_2} = \text{const}; \quad (2)$$

– spherical joint $B_3$:

$$x_{B_3} = x_{O_1} + l_{O_1B_3}\cdot\sin\varphi_1, \qquad y_{B_3} = y_{O_1} + l_{O_1B_3}\cdot\cos\varphi_1, \qquad z_{B_3} = \text{const}; \quad (3)$$

– spherical joint $B_4$:

$$x_{B_4} = x_{O_1} + l_{O_1B_4} \cdot \sin(\alpha + \varphi_1), \qquad y_{B_4} = y_{O_1} + l_{O_1B_4} \cdot \cos(\alpha + \varphi_1), \qquad z_{B_4} = \text{const}. \tag{4}$$

The coordinates $z_{B_2}$, $z_{B_3}$, $z_{B_4}$ are considered constant, and their values are adopted based on the developed design of the manual control mechanism.

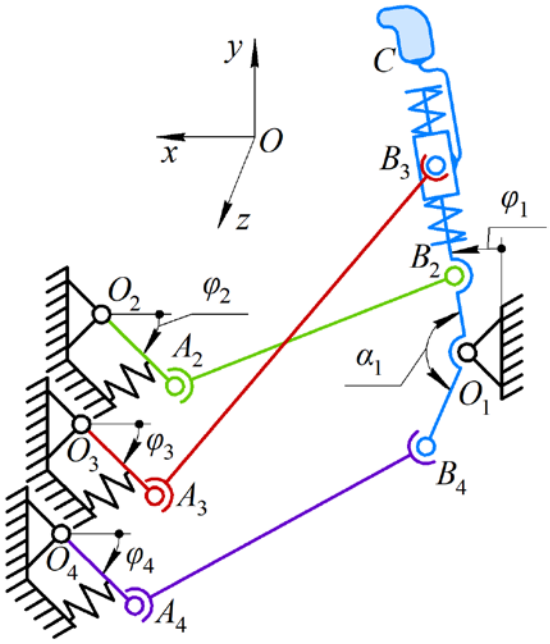


*Fig. 1. Structural scheme of the proposed mechanism for manual control of three motor vehicle pedals*

In order to determine the coordinates of the hinges $A_2$, $A_3$, $A_4$ as functions of the considered generalized coordinates, let us use the method of closed vector loops to derive the following systems of equations for the kinematic chains of each pedal:

– accelerator pedal:

$$\begin{aligned} &(x_{A_2} - x_{B_2})^2 + (y_{A_2} - y_{B_2})^2 + (z_{A_2} - z_{B_2})^2 - (l_{A_2B_2})^2 = 0; \\ &(x_{A_2} - x_{O_2})^2 + (y_{A_2} - y_{O_2})^2 + (z_{A_2} - z_{O_2})^2 - (l_{A_2O_2})^2 = 0; \end{aligned} \tag{5}$$

– brake pedal:

$$\begin{aligned} &(x_{A_3} - x_{B_3})^2 + (y_{A_3} - y_{B_3})^2 + (z_{A_3} - z_{B_3})^2 - (l_{A_3B_3})^2 = 0; \\ &(x_{A_3} - x_{O_3})^2 + (y_{A_3} - y_{O_3})^2 + (z_{A_3} - z_{O_3})^2 - (l_{A_3O_3})^2 = 0; \end{aligned} \tag{6}$$

– clutch pedal:

$$\begin{aligned} &(x_{A_4} - x_{B_4})^2 + (y_{A_4} - y_{B_4})^2 + (z_{A_4} - z_{B_4})^2 - (l_{A_4B_4})^2 = 0; \\ &(x_{A_4} - x_{O_4})^2 + (y_{A_4} - y_{O_4})^2 + (z_{A_4} - z_{O_4})^2 - (l_{A_4O_4})^2 = 0. \end{aligned} \tag{7}$$

The parameters $z_{A_2}$, $z_{A_3}$, $z_{A_4}$, $x_{O_2}$, $x_{O_3}$, $x_{O_4}$, $y_{O_2}$, $y_{O_3}$, $y_{O_4}$, $z_{O_2}$, $z_{O_3}$, $z_{O_4}$, $l_{A_2O_2}$, $l_{A_3O_3}$, $l_{A_4O_4}$ depend on the design peculiarities of a specific model of a motor vehicle and are considered constant.

Solving the system of equations (5)–(7) with the help of the Wolfram Mathematica software allows for obtaining the analytical expressions for the coordinates of the joints $A_2$, $A_3$, $A_4$:

$$
x_{A_i}=\frac{\left[\begin{aligned}
&-\left(l_{A_iB_i}\right)^2\cdot x_{B_i}+\left(l_{A_iO_i}\right)^2\cdot x_{B_i}+\left(x_{B_i}\right)^3+\left(l_{A_iB_i}\right)^2\cdot x_{O_i}-\left(l_{A_iO_i}\right)^2\cdot x_{O_i}-\left(x_{B_i}\right)^2\cdot x_{O_i}-\\
&-x_{B_i}\cdot\left(x_{O_i}\right)^2+\left(x_{O_i}\right)^3+\left(x_{B_i}+x_{O_i}\right)\cdot\left(y_{O_i}\right)^2-2\cdot\left(x_{B_i}+x_{O_i}\right)\cdot y_{B_i}\cdot y_{O_i}+x_{B_i}\cdot\left(y_{O_i}\right)^2+\\
&+x_{O_i}\cdot\left(y_{O_i}\right)^2-2\cdot x_{B_i}\cdot z_{A_i}\cdot z_{B_i}+2\cdot x_{O_i}\cdot z_{A_i}\cdot z_{B_i}+x_{B_i}\cdot\left(z_{B_i}\right)^2-x_{O_i}\cdot\left(z_{B_i}\right)^2+\\
&+2\cdot x_{B_i}\cdot z_{A_i}\cdot z_{O_i}-2\cdot x_{O_i}\cdot z_{A_i}\cdot z_{O_i}-x_{B_i}\cdot\left(z_{O_i}\right)^2+x_{O_i}\cdot\left(z_{O_i}\right)^2\pm\\
&\pm\sqrt{\left(-\left(y_{B_i}-y_{O_i}\right)^2\cdot\left(\begin{aligned}
&\left(l_{A_iB_i}\right)^4+\left(l_{A_iO_i}\right)^4-2\cdot\left(l_{A_iO_i}\right)^2\cdot\left(\begin{aligned}&\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\\&+\left(2\cdot z_{A_i}-z_{B_i}-z_{O_i}\right)\cdot\left(z_{B_i}-z_{O_i}\right)\end{aligned}\right)-\\
&-2\cdot\left(l_{A_iB_i}\right)^2\cdot\left(\begin{aligned}&\left(l_{A_iO_i}\right)^2+\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2-\\&-2\cdot z_{A_i}\cdot z_{B_i}+\left(z_{B_i}\right)^2+2\cdot z_{A_i}\cdot z_{O_i}-\left(z_{O_i}\right)^2\end{aligned}\right)+\\
&+\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\left(z_{B_i}-z_{O_i}\right)^2\right)\times\\
&\times\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\left(-2\cdot z_{A_i}+z_{B_i}+z_{O_i}\right)^2\right)
\end{aligned}\right)\right)}
\end{aligned}\right]}{2\cdot\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2\right)};
$$

$$
y_{A_i}=\frac{\left[\begin{aligned}
&-\left(l_{A_iB_i}\right)^2\cdot\left(y_{B_i}-y_{O_i}\right)^2+\\
&+\left(y_{B_i}-y_{O_i}\right)\cdot\left(\begin{aligned}
&\left(x_{O_i}\right)^2\cdot y_{B_i}+\left(y_{B_i}\right)^3+\left(l_{A_iO_i}\right)^2\cdot\left(y_{B_i}-y_{O_i}\right)+\left(x_{O_i}\right)^2\cdot y_{O_i}-\left(y_{B_i}\right)^2\cdot y_{O_i}-\\
&-y_{B_i}\cdot\left(y_{O_i}\right)^2+\left(y_{O_i}\right)^3+\left(x_{B_i}\right)^2\cdot\left(y_{B_i}+y_{O_i}\right)-2\cdot x_{B_i}\cdot x_{O_i}\cdot\left(y_{B_i}+y_{O_i}\right)-\\
&-2\cdot y_{B_i}\cdot z_{A_i}\cdot z_{B_i}+2\cdot y_{O_i}\cdot z_{A_i}\cdot z_{B_i}+y_{B_i}\cdot\left(z_{B_i}\right)^2-y_{O_i}\cdot\left(z_{B_i}\right)^2+\\
&+2\cdot\left(y_{B_i}-y_{O_i}\right)\cdot z_{A_i}\cdot z_{O_i}-\left(y_{B_i}-y_{O_i}\right)\cdot\left(z_{O_i}\right)^2
\end{aligned}\right)\pm\\
&\pm\left(x_{O_i}-x_{B_i}\right)\times\\
&\sqrt{\left(-\left(y_{B_i}-y_{O_i}\right)^2\cdot\left(\begin{aligned}
&\left(l_{A_iB_i}\right)^4+\left(l_{A_iO_i}\right)^4-2\cdot\left(l_{A_iO_i}\right)^2\cdot\left(\begin{aligned}&\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\\&+\left(2\cdot z_{A_i}-z_{B_i}-z_{O_i}\right)\cdot\left(z_{B_i}-z_{O_i}\right)\end{aligned}\right)-\\
&-2\cdot\left(l_{A_iB_i}\right)^2\cdot\left(\begin{aligned}&\left(l_{A_iO_i}\right)^2+\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2-\\&-2\cdot z_{A_i}\cdot z_{B_i}+\left(z_{B_i}\right)^2+2\cdot z_{A_i}\cdot z_{O_i}-\left(z_{O_i}\right)^2\end{aligned}\right)+\\
&+\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\left(z_{B_i}-z_{O_i}\right)^2\right)\times\\
&\times\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2+\left(-2\cdot z_{A_i}+z_{B_i}+z_{O_i}\right)^2\right)
\end{aligned}\right)\right)}
\end{aligned}\right]}{2\cdot\left(\left(x_{B_i}-x_{O_i}\right)^2+\left(y_{B_i}-y_{O_i}\right)^2\right)\cdot\left(y_{B_i}-y_{O_i}\right)}. \qquad (8)
$$

The inclination angles $\varphi_2$, $\varphi_3$, and $\varphi_4$ of each pedal can be determined as follows:

$$\varphi_i = \text{arctg}\left(\frac{y_{O_i} - y_{A_i}}{x_{O_i} - x_{A_i}}\right). \tag{9}$$

As an example, let us perform the analysis of kinematic characteristics of the proposed manual control mechanism considering the following geometrical parameters: $l_{A_2B_2} = 806$ mm, $l_{A_3B_3} = 750$ mm, $l_{A_4B_4} = 812$ mm, $l_{O_1B_2} = 100$ mm, $l_{O_1B_4} = 117$ mm, $l_{A_2O_2} = 150$ mm, $l_{A_3O_3} = 300$ mm, $l_{A_4O_4} = 200$ mm, $\alpha = 180°$, $x_{O_1} = y_{O_1} = z_{O_1} = z_{B_2} = z_{B_3} = z_{B_4} = 0$ mm, $x_{O_2} = 830$ mm, $y_{O_2} = -100$ mm, $z_{O_2} = 185$ mm, $x_{O_3} = 820$ mm, $y_{O_3} = -110$ mm, $z_{O_3} = 300$ mm, $x_{O_4} = 810$ mm, $y_{O_4} = -120$ mm, $z_{O_4} = 420$ mm, $z_{A_2} = 185$ mm, $z_{A_3} = 300$ mm, $z_{A_4} = 420$ mm. The parameters $\varphi_1$ and $l_{O_1B_3}$ are considered controllable (changeable).

The numerical simulation is carried out using the Wolfram Mathematica software. The obtained plots allow for analyzing the pedals' kinematic behavior during the driver's control actions. Considering the pushing-puling movements of the handle in the proposed manual control mechanism, i.e., only the change in the inclination angle $\varphi_1$ within the range of –30°…+30°, let us plot the motion trajectories $\left(y_{A_2}\left(x_{A_2}\right), y_{A_4}\left(x_{A_4}\right)\right)$ and the dependencies of the treadle angles ($\varphi_2$, $\varphi_4$) of the accelerator and clutch pedals (see Fig. 2). In general, the pedals rotate around the hinges connecting them with the motor vehicle frame. The corresponding arc-type trajectories of the hinges connecting the pedals with the push-pull rods are shown in Fig. 2, *a*. The *y*-axis displacements vary in the range of approximately –236 mm to –161 mm for the accelerator pedal and from –300 mm to –205 mm for the clutch pedal. The displacements along the *x*-axis change within 765–695 mm for the accelerator pedal and within 725–630 mm for the clutch pedal. The dependencies of the pedals' treadle angles $\varphi_2$ and $\varphi_4$ on the control handle inclination angle $\varphi_1$ are shown in Fig. 2, *b*. When the control handle is maximally pulled ($\varphi_1$ = –30° = –0.52 rad), the accelerator pedal is inclined to the horizontal axis at the smallest angle $\varphi_2$ = 24°. At the same position as the handle, the clutch pedal forms the largest 64-degree angle with the horizontal axis. On the other hand, when the control handle is pushed forward at the maximal angle of +30° (0.52 rad), the accelerator pedal makes the largest angle $\varphi_2$ = 64° with the horizontal axis, while the clutch pedal is inclined at the slightest angle of approximately 24°. Therefore, by moving the handle forward and backward, i.e., performing the push-pull movements, the driver can control the angular position of the accelerator and clutch pedals within the range of about 40° to manually shift gears and provide other driving functions.

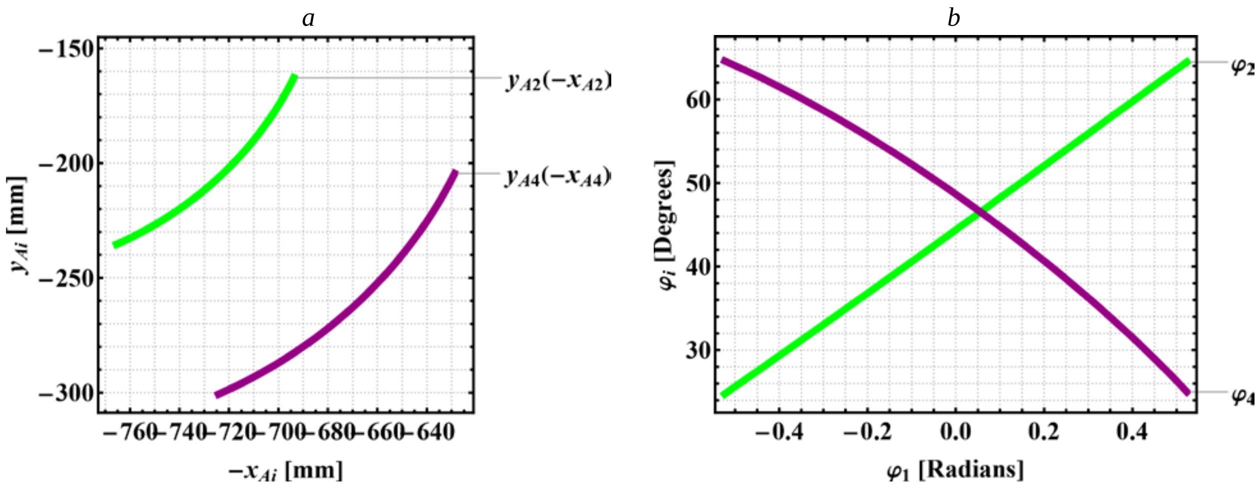


*Fig. 2. Kinematic characteristics of the accelerator and clutch pedals: a – trajectories of hinges connecting pedals with push-pull rods; b – dependencies of pedals' treadle angles on the control handle inclination angle*

The next stage of these investigations deals with modeling the movements of the brake pedal caused by pressing the control handle downwards or lifting it upwards. In general, the upward and downward movements of the handle are not restricted when pushing forward or pulling backward. The corresponding slider can move along the guide connected with the control lever. The springs that hold the handle are much weaker than those that support the brake pedal (connected between the pedal and the motor vehicle's frame). Therefore, during the push-pull movements of the handle, it freely moves upwards and downwards and does not push or pull the brake pedal.

Let us first consider the maximal upward-downward displacements of the control handle during its pushing and pulling movements. These dependencies are important for further designing the manual control mechanism and calculating the corresponding holding springs. Solving the system of equations (6) concerning the coordinates $x_{B_3}$, $y_{B_3}$ of the control handle's slider in the Mathematica software, and taking into consideration the analytical expressions (3), we obtain:

$$l_{O_1B_3}=\begin{pmatrix}\left(y_{A_3}-y_{O_1}\right)\cdot\cos\varphi_1+\\+\left(x_{A_3}-x_{O_1}\right)\cdot\sin\varphi_1\end{pmatrix}\pm\sqrt{\begin{matrix}\left(\left(y_{A_3}-y_{O_1}\right)\cdot\cos\varphi_1+\left(x_{A_3}-x_{O_1}\right)\cdot\sin\varphi_1\right)^2-\\-\left(\left(y_{A_3}-y_{O_1}\right)^2+\left(x_{A_3}-x_{O_1}\right)^2+\left(z_{A_3}-z_{B_3}\right)^2-\left(l_{A_3B_3}\right)^2\right)\end{matrix}}. \tag{10}$$

Before starting the analysis of the displacements and trajectory of the control handle's slider, it is necessary to define the coordinates of the hinge $A_3$, which connects the corresponding push-pull rod with the brake pedal at its free state, i.e., at the minimal inclination angle $\varphi_{3\min}$ = 24°:

$$\begin{gathered}x_{A_3}=x_{O_3}-l_{A_3O_3}\cdot\cos\varphi_{3\min}=820-300\cdot\cos24°=546\text{ mm};\\y_{A_3}=y_{O_3}-l_{A_3O_3}\cdot\sin\varphi_{3\min}=-110-300\cdot\sin24°=-232\text{ mm};\\z_{B_3}=\text{const}=0\text{ mm}.\end{gathered} \tag{11}$$

Considering the above-mentioned geometrical parameters of the brake pedal links and adopting the same minimal and maximal inclination angles of the brake pedal $\varphi_{3\min}$ = 24°, $\varphi_{3\max}$ = 64° and the control lever $\varphi_{1\min}$ = –30°, $\varphi_{1\max}$ = 30°, let us plot the corresponding graphical dependence of the handle slider displacement (Fig. 3, *a*) and its motion trajectory (Fig. 3, *b*) based on the analytical expressions (3) and (10). When the control handle is maximally pulled ($\varphi_{1\min}$ = –30°), the distance $l_{O_1B_3}$ takes its minimal value of approximately 110 mm. If the handle is maximally pushed forward ($\varphi_{3\max}$ = 30°), the slider moves along the corresponding guide at the largest distance of about 420 mm. The horizontal displacement of the slider varies in the range of –55–210 mm, while its vertical displacement changes from 90 mm to 360 mm.

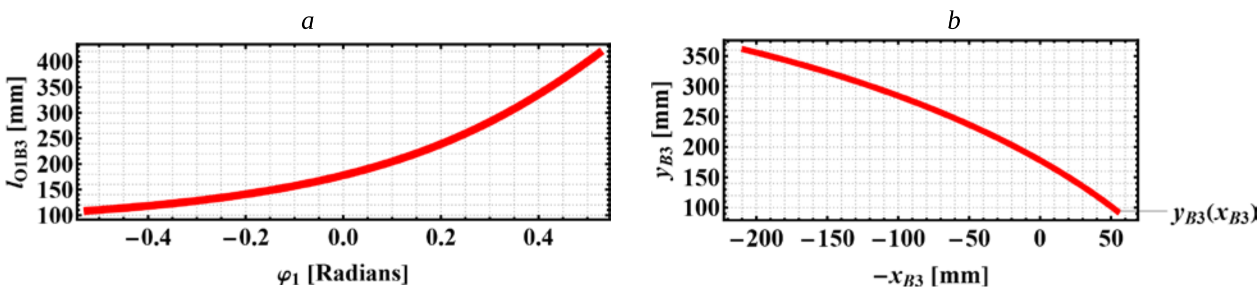


*Fig. 3. Kinematic characteristics of the brake handle: a – dependency of the handle slider displacement on its inclination angle; b – trajectory of the brake handle slider*

Finally, let us determine the dependency of the brake pedal treadle angle $\varphi_3$ on the position of the slider $l_{O1B3}$ and the trajectory of the hinge $A_3$ connecting the corresponding push-pull rod with the brake pedal at the handle's maximally pulled position using the analytical expressions (8) and (9). Considering the influence of the handle displacement $l_{O_1B_3}$ along the slider's guide on the brake pedal treadle angle $\varphi_3$

(see Fig. 4, *a*), it is observed that the latter varies within the range of 24–64° due to the changes in the $l_{O1B3}$ length from approximately 110 mm to –120 mm. These changes allow for the connecting hinge of the brake pedal to describe the trajectory shown in Fig. 4(*b*). The lowest position of the pedal is defined by the horizontal and vertical coordinates of the hinge $A_3$: $x_{A_3 low} = 690$ mm, $y_{A_3 low} = -380$ mm, while the highest position is characterized by the following coordinates: $x_{A_3 high} = 546$ mm, $y_{A_3 high} = -232$ mm.

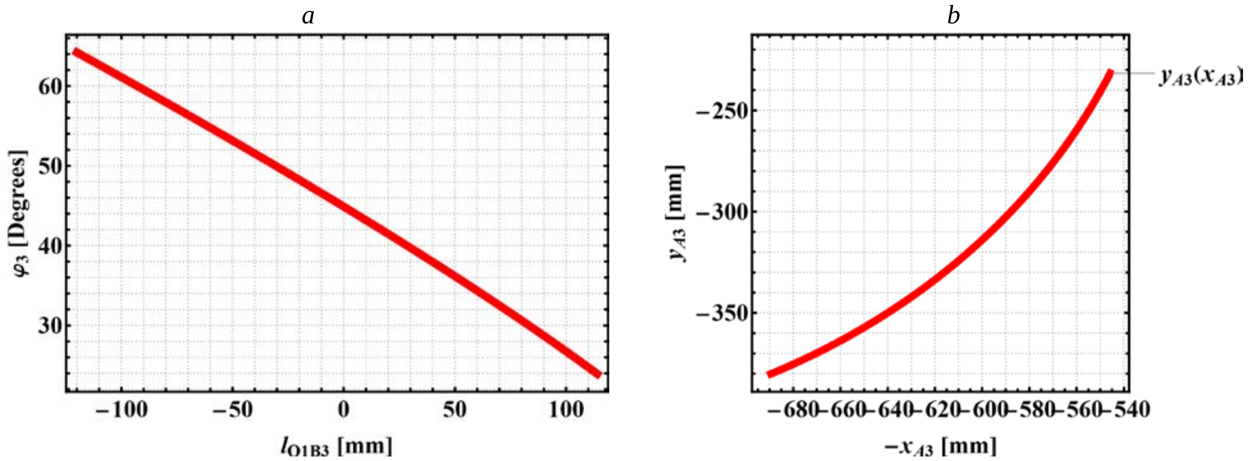


*Fig. 4. Kinematic characteristics of the brake pedal: a – dependency of the brake pedal treadle angle on the position of the handle slider; b – trajectory of the brake pedal's hinge*

## 5. 3D-DESIGN AND OPERATIONAL PECULIARITIES OF THE IMPROVED MECHANISM

Based on the carried-out structural synthesis and kinematic analysis of the improved mechanism for simultaneous manual control of three pedals of a motor vehicle, the corresponding 3D-design is developed in the SolidWorks software (see Fig. 5). The proposed mechanism consists of the handle 1, which is fixed on the sliding rod 16. The latter is hinged by the spherical joint 3 to the push-pull rod 4 of a brake pedal. The displacement of the sliding rod 16 along the corresponding guide is restricted by springs 2 and 15. In such a case, the handle 1 can be pushed forward or pulled backward without any impact on the brake pedal. The rocker arm 14 is installed on the mechanism frame 11 with the help of the special ratchet gear 12, allowing for fixing the angular position of the handle 1 without the necessity to hold it continuously by hand. It provides the possibility for the driver to shift gears. The upper section of the rocker arm 14 is hinged by the spherical joint 13 to the push-pull rod 5 of the accelerator pedal. The lower section of the rocker arm 14 is hinged by the spherical joint 6 to the push-pull rod 7 of the clutch pedal. The push-pull rods 4, 5, and 7 are hinged to the corresponding pedals with the help of the spherical joints 8, 9, and 10, respectively. The mechanism is mounted on the motor vehicle's body through frame 11.

In order to actuate the accelerator pedal, the driver needs to push the control handle forward. At the same time, the clutch pedal is slowly becoming released. To shift gears, the driver should pull the control handle towards himself, engaging the clutch pedal and releasing the accelerator pedal. At this moment, the gear lever should be adjusted to the desired gear. Then, the driver should gradually press the control lever forward to engage the accelerator pedal while disengaging the clutch pedal. To decelerate the vehicle slightly, the driver needs to apply gentle downward pressure on the control handle. The handle should be pulled towards the driver and pressed downward for a full stop or emergency braking. The clutch and brake pedals are fully engaged in this process, and the accelerator pedal is released.

Therefore, unlike the previously considered mechanisms intended for manual control of the motor vehicle's pedals [1]–[17], the proposed structure of the improved mechanism (Figs. 1 and 5) allows for simultaneous control of three pedals: accelerator, brake, and clutch. The corresponding geometrical parameters of the mechanism's links may be easily synthesized for different models of motor vehicles by using the derived analytical expressions (2)–(11) and by adopting the corresponding restrictions on the links' lengths imposed by the vehicles' designs. The following investigations on the subject of the paper are to be focused on developing the full-scale experimental prototype of the device for manual control of the motor vehicle's pedals and its testing under different working regimes. The obtained results may be used by researchers and designers of similar devices while enhancing the existent designs of the manual control mechanisms and creating new structures based on the considered mechanism.

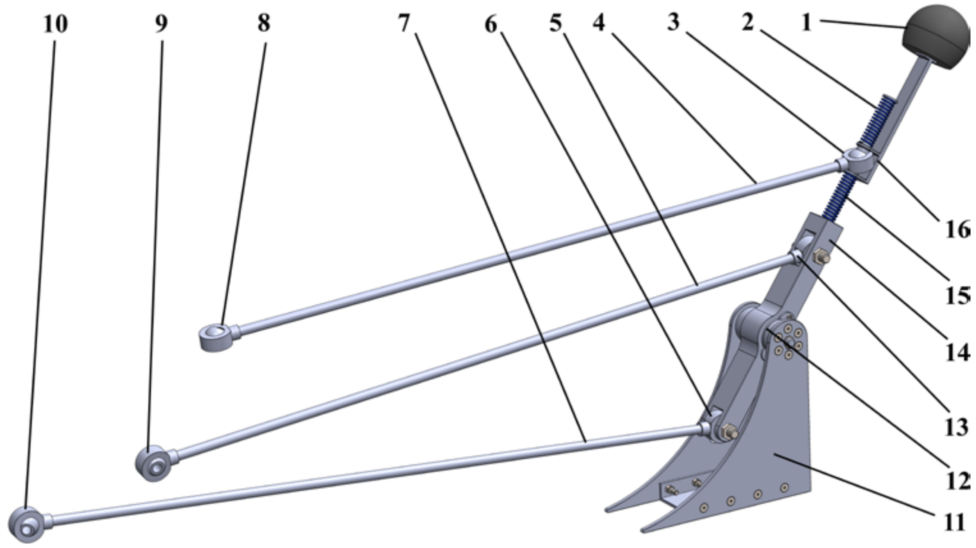


*Fig. 5. 3D-design of the improved mechanism for manual control of three motor vehicle pedals*

## 6. CONCLUSIONS

Individuals with physical disabilities face significant challenges when operating standard vehicles due to their inability to use traditional foot pedals. There is a pressing need for innovative and adaptable pedal control systems to address this issue. These systems should be designed to accommodate the specific requirements of disabled drivers, ensuring both safety and ease of use. Developing specialized manual control devices, such as hand-operated pedals or adjustable foot controls, enables disabled drivers to navigate the roads independently and confidently.

This research focuses on developing an enhanced manual control mechanism for vehicle pedals. The goal is to create a device that allows simultaneous control of the accelerator, brake, and clutch using only one hand. A comprehensive review of existing prototypes reveals a significant limitation: most mechanisms only provide control for two pedals, limiting their applicability to automatic or electric vehicles. While a few mechanisms have been designed for three-pedal control, they typically require both hands, compromising driving safety. This study aims to improve existing designs by developing a mechanism that enables one-handed control of all three pedals to address these shortcomings.

The research methodology employs established principles from the field of mechanisms and machines to design a novel multi-link hinge-lever mechanism. Through kinematic analysis, the study determines the main parameters governing pedal movements in response to various hand inputs. The findings from this research can be applied by researchers and engineers to further refine manual control mechanisms for vehicle pedals and facilitate their practical implementation. Future research directions include the development of an experimental prototype, followed by rigorous testing and adjustment to ensure compatibility with different vehicle models and optimize driving performance, comfort, and safety.

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Received 10.09.2024; Accepted in revised form 05.11.2024.

# ОБҐРУНТУВАННЯ СТРУКТУРИ УДОСКОНАЛЕНОГО МЕХАНІЗМУ РУЧНОГО КЕРУВАННЯ ПЕДАЛЯМИ АВТОМОБІЛЯ

***Анотація.*** *Зважаючи на складну військову ситуацію в Україні, попит на індивідуально налаштовані та гнучкі системи керування педалями автомобіля для осіб із обмеженими фізичними можливостями є особливо великим. Стандартні конфігурації педалей часто не відповідають специфічним потребам водіїв із обмеженою рухливістю ніг, що ускладнює керування транспортним засобом і може бути небезпечним. Розробки, пов'язані зі створенням спеціалізованих механізмів ручного керування педалями або регульованих ножних педаль, вирішальні для забезпечення комфортності для цих водіїв та безпеки керування. Такі інновації не тільки підвищують доступність автомобільного транспорту, але і сприяють* *підвищенню самостійності та інклюзії, забезпечуючи водіям із обмеженими фізичними можливостями впевненості та безпечності під час керування автомобілем.*

*У статті здійснено огляд наявних прототипів механізмів для ручного керування педалями автомобіля та розроблення удосконаленого пристрою із можливістю одночасного керування однією рукою одразу трьома педалями – акселератора, гальма та зчеплення. У результаті патентного огляду низки наявних прототипів механізмів керування зроблено висновок, що переважна більшість із них забезпечують керування лише двома педалями – акселератора і гальм, тобто можуть використовуватися виключно на автомобілях із автоматичними коробками передач або на електромобілях. Лише окремі механізми розроблено для керування трьома педалями, але із необхідністю використання обох рук водія, що безпосередньо впливає на безпеку руху. Тому актуальним залишається удосконалення наявних конструкцій механізмів керування трьома педалями із переведенням усіх керуючих функцій на одну руку водія.*

*Методологія досліджень передбачає використання класичних методів теорії механізмів і машин для виконання структурного синтезу удосконаленого багатоланкового шарнірно-важільного механізму та його кінематичного аналізу з метою встановлення основних параметрів руху педалі автомобіля за різних керуючих впливів руки водія. Отриманими результатами можуть скористатися дослідники й інженери для подальшого удосконалення конструкцій механізмів ручного керування педалями автомобілів та під час їх практичного впровадження. Перспективи подальших досліджень за цією тематикою полягають у розробленні експериментального прототипу механізму керування та його апробації й налаштуванні для різних модифікацій автомобілів з метою підвищення плавності ходу, а також комфортності й безпеки водіння.*

***Ключові слова:*** *керування транспортним засобом, комфортність руху, безпека руху, плавність ходу, структурний синтез, кінематичний аналіз, параметри руху.*