Specific features of mobile machine reverse movement

A S Pavlyuk, V I Poddubniy and A S Baranov
Altay State Technical University, 46 Lenina avenue, Barnaul, 656038, Russia

Abstract. The study deals with questions related to mobile machine manoeuvring when reversing. When the mobile machine is moving backward kinematics of processing various manoeuvres coincides with kinematics of forward movement. This fact gives the possibility to use analytical dependences obtained when the mobile machine is moving forward to describe reverse movement. To estimate the effectiveness of training mobile machine driving when moving backward both laboratory research using a hardware and software complex and full-scale tests using an automobile were conducted. The process of simulation the driver’s impact on the mobile machine steering system when moving backward is effectively implemented using a hardware and software complex. Maximal discrepancies in the results of theoretical and experimental studies do not exceed 10…15 per cent. The obtained results of experiments with an automobile were close to the results of experiments with hardware and software complex, the divergence was relatively small: from 3 to 9 per cent. This fact confirms the possibility of using the given complex to impart elementary skills of driving a mobile machine when moving backward. To simplify driving a mobile machine when moving backward the method of driving a mobile machine when moving backward was suggested.

1. Introduction
One of the most important operational and technical properties of mobile machines is manoeuvrability. The manoeuvrability of the mobile machine has a direct impact on its performance. For transport vehicles, an increase in manoeuvrability leads to a decrease in time for loading and unloading operations, manoeuvring time in industrial premises when they are placed at storage sites or at maintenance and repair posts. Increasing the manoeuvrability of machine and tractor units reduces idle unproductive runs.

The main types of manoeuvres of mobile vehicles are a turn of 90 degrees, a turn of 180 degrees and angles close to them, a lane change or “relocation”.

The issues of manoeuvring when moving forward are studied in details, there are many recommendations for the use of rational methods of driving mobile cars. At the same time, in conditions of limited manoeuvring area, reversing is used, for example, when setting up a mobile car for maintenance and repair posts in production premises, entering and leaving at loading or unloading points.

Reverse movement of mobile vehicles is the most difficult and not only in conditions of limited space. There are a number of works of foreign researchers devoted to the study of the possibility of reverse automatic parking of the road trains. [1,2] At the same time, the issues of manoeuvring when reversing are not fully understood, there are no specific recommendations for teaching students to drive when the vehicle is reversing.
2. The purpose of the research
The purpose of the research is to substantiate the possibility of using analytical dependencies describing the reverse movement of a mobile vehicle i.e. to describe reversing, to develop methods of teaching reverse driving, and also to facilitate control of the mobile car when reversing.

3. Conditions and methods
For the purpose of modelling the controlled movement of cars, obtaining recommendations for driving instruction, it seems appropriate to determine rational forms of control actions uniquely associated with the type of manoeuvre being performed [3].

Let us consider the kinematics of manoeuvring when reversing mobile vehicles. Due to the reversibility of the guide point trajectory, the forward movement can be replaced by the reverse movement. The kinematics of the manoeuvre will remain the same. At the initial stage, we will introduce a number of limitations and assumptions. The movement occurs on a horizontal solid support surface with low speeds, lateral withdrawal of pneumatic tires is not taken into account, there is no vertical movement and roll of the sprung mass, steerable wheels are turned to the maximum angle.

Figure 1 shows a diagram of the manoeuvre for the correction of the lateral displacement ("permutation"). We believe that the movement is determined by the trajectory of the guide point located in the middle of the front axle.

Manoeuvre analysis will begin with the formalization of the problem statement. The purpose of the manoeuvre is to move the mobile vehicle in the process of movement on a parallel trajectory, separated from the original at a distance of $H$.

In this case, the driver chooses the distance $L$ at which this manoeuvre should be completed basing on external factors, such as speed, road conditions, traffic intensity on the road. Thus, the manoeuvre can be described as the movement of a mobile machine, in which the guide point moves from the starting point $O$ to the end point $K$, the tangents to the trajectory in which are parallel and separated from each other at a distance $H$, and the distance from the point $O$ to the projection of the point $K$ on the tangent to the trajectory at the point $O$ is equal to $L$.

By presenting the trajectory of the mobile machine next to Fourier [4], it is advisable to represent the turning law of the steered wheels when studying the behaviour of the mobile vehicle at the “resetting” manoeuvre by the following piecewise function:

\[
\alpha = \begin{cases} 
\frac{2\pi H}{L} \sin \left( \frac{2\pi x}{L} \right) & \text{when } x \in \left[ \frac{L}{4}, \frac{3L}{4} \right] \\
\frac{\pi H}{L} \left( 1 - \frac{4\pi x}{L} \right) & \text{when } x \in \left[ 0, \frac{L}{4} \right] \\
\frac{\pi H}{L} \left( \cos \frac{4\pi x}{L} - 1 \right) & \text{when } x \in \left[ \frac{3L}{4}, L \right].
\end{cases}
\]

Figure 2 shows the recommended form of control in a “reshuffle” manoeuvre. In the graph of the dependence of the rotation average angle of the steered wheels on the longitudinal displacement, only the first quarter of the manoeuvre period corresponds to the manoeuvre of the trajectory curvature correction, the first and fourth quarters to the manoeuvre of the angular correction.

In case of the use of other control actions indicators of the parameters of controlled motion deteriorate. Thus, when choosing the rotation angles of the steered wheels with different magnitudes in the left and right parts of the graph in figure 4, it is necessary to have an additional control action.
The termination of the steering wheel rotation in any period of manoeuvre leads to the necessity of turning the steering wheels to a larger angle, which leads to an increase in the maximum lateral acceleration, as well as to a longer duration of manoeuvre. Deviations from the specified forms of changing the angle of the steered wheel rotation leads to an increase in the force on the drive, etc.

The results of theoretical and experimental studies of mobile machine controllability, given in [3], are in good agreement with each other, they also agree with the results obtained by foreign scientists [5, 6].

The main purpose of the experimental research was to determine the relationship between the forms of control actions and the resulting vehicle movement paths.

Laboratory tests were carried out on a hardware-software complex consisting of a personal computer, a specialized joystick simulating the controls of a mobile machine (steering wheel, fuel pedal and brake pedals, gearbox control lever) and software.

For research, drivers of category B and C were involved, the task of which was to hold the image of the car on the display, at a constant speed, inside a given corridor of motion, turning the steering wheel. The control accuracy was estimated by the number of control actions, lateral acceleration, and the width of the movement corridor.

Road tests were carried out on the example of a VAZ-2104 with a computer installed on it with a satellite radio navigation system receiver connected. Also, the sensors of the rotation angle of the steering wheel shaft were connected to the computer.

Driving at the same time was made in two ways. In the first version, preliminary marking of the required trajectory was carried out. The driver, arbitrarily turning the steering wheel, tried to provide a valid trajectory as close as possible to the desired one.

In the second variant, the driver, when performing the maneuver while turning the steering wheel, was guided by the desired trajectory shown on the computer display, the current position of the vehicle and the actual trajectory. The image on the display was created on the basis of signals from the receiver of a satellite radio navigation system.

The shape of the control actions was determined by the readings of the steering angle sensors installed on the vehicle, depending on the time.

The greatest efficiency is ensured by the way in which, based on the performance of the satellite radio navigation system receiver, the computer display shows the shape of the actual vehicle trajectory associated with the system of geographical coordinates. The processing of incoming information is carried out using a specialized program of work with a satellite receiver.

In the framework of scientific research, the software of the firm "Ingit" (St. Petersburg) GisMaster 4.1 was used, which allows to realize various ways of using a satellite receiver in the field and road.
In experimental studies, it was determined that the forms of driver control actions in various driving conditions are rational to the forms of the trajectory of movement.

4. Results and discussions
To determine the actual forms of driver control actions, two types of experiments were carried out. In the experiments of the first type, the abovementioned hardware-software complex was used.

The operator had to perform the specified manoeuvre at a constant value of speed being guided by the position of the image of the car relative to the marking. We used such indicators of controllability as: the number of control actions, the maximum value of the lateral acceleration of the centre of mass of the vehicle.

The maneuver was considered executed when the image of the car did not go beyond the bounding lines while moving. For each maneuver, the graphic dependences of the lateral displacement of the center of mass of the machine on the longitudinal movement were determined, as well as the values of the steering wheel angle and lateral acceleration of the center of mass corresponding to these dependencies.

14 operators participated in the experiments - drivers of category “B”, with work experience from 1 to 27 years.

The research results showed that, despite the fact that the forms of transition curves and control actions in the experiments were not predetermined and specified, there was an improvement in the estimated controllability indicators (decrease in the number of control actions and a decrease in the maximum lateral acceleration) impacts to certain above in all experiments.

Figure 3 shows samples of graphical dependences of the steering wheel angle and lateral displacement from longitudinal movement and travel time when the operator performs a “reset” manoeuvre.

The dashed lines denote the theoretical forms of control actions described by theoretical dependence.

In the transition from the rectilinear motion of the centre of mass to the circumferential motion, the character of rotation of the steered wheels is close to a turn with a constant angular velocity, i.e. with a linear increase in the rotation angle of the wheels. At the end of the turn, the rotation speed smoothly changes to zero, preventing a sharp change in angular velocity and reducing the maximum lateral acceleration value.

Experiments of the second type were carried out on a VAZ-2104 passenger car. Installed equipment recorded the speed, course angle, distance traveled, steering angle, time of motion. The movement was carried out on a predetermined marking of the support surface.
Figure 4 shows the graphs of changes in the steering angle and lateral displacement of the vehicle as a function of the longitudinal movement during the "resetting" maneuver, obtained using an optical sensor for the steering angle and the satellite navigation receiver together with a personal portable computer.

The experiments were carried out when driving on roads with asphalt concrete pavement, dirt roads. The car load varied from the minimum (driver), to the maximum including the driver, four passengers and 150 kg of cargo.

Analysis of the location of the curves in the graphs indicates that the experimental dependences are close to the theoretical ones. The maximum discrepancies do not exceed 10–15%.

It was found that when performing maneuvers of the second type, results obtained were close to the results of experiments of the first type. Deviations were relatively small and amounted to 3 - 9%.

Based on the analysis obtained, a method was developed for controlling a mobile vehicle when reversing [7].

The objective of this method is to expand the functionality of the reverse movement of the mobile vehicle.

The task is achieved by the method of controlling a mobile machine, the determination the position change direction of the mobile vehicle is carried out by recording the dependence of the angle of rotation of the controlled wheel periodically or continuously from the previously traveled path when determining the direction of advance, and reproduce in the reverse order of the recording when moving backwards.

5. Conclusion

Analytical dependences of the movement kinematics of single mobile vehicles, obtained by researchers for forward movement, can be used to analyse reverse manoeuvrability.

The study of the driver as a car control unit is possible on simplified generalized models used in laboratory experiments without significant errors.

It is advisable to work out the typical forms of control actions when training driving a car on simulators and in real conditions, and also to use it in mathematical models for modelling controlled movement.

The proposed method of controlling a mobile vehicle when reversing will greatly facilitate the management process, especially for a driver with insufficient experience.

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