UDC 629.3.012 https://doi.org/10.23947/2541-9129-2020-3-33-38

# Evaluation of safety parameters of the motor grader during maneuvering in the street and road network

**V. V. Deryushev, E. E. Kosenko, V. V. Kosenko**
Don State Technical University (Rostov-on-Don, Russian Federation)

*Introduction.* The article is devoted to improving the safety of operation of motor graders in urban conditions. The paper considers analytical methods for evaluating the influence of structural, geometric and kinematic characteristics of the motor grader on the safety of maneuvering in urban conditions for u-turns and turns at the intersections of the road network.

*Problem Statement.* In the course of the study, it is necessary to establish safe values of kinematic and geometric parameters for maneuvering of motor graders with articulated frames in urban conditions.

*Theoretical Part.* The numerical estimates were made based on the technical characteristics of three types of articulated frame graders. We consider possible options for moving the grader out of the street or roadway when making a "right" or "left" turn at a road intersection to avoid the situation of moving the grader out of the street or roadway. The calculation scheme for determining the parameters of the motor grader's turn is constructed.

The calculation formulas for the external and internal overall turning radii of the grader and the overall traffic corridor are obtained. This allows you to determine the minimum width of the roadway for safe maneuvering of the motor grader. The value of the required safe minimum turning radius of the motor grader for a given width of the roadway is determined. All calculation formulas are obtained for the general case when the trajectories of the rear and front wheels do not coincide. It is shown that when turning the motor grader, the most dangerous is the radius of the front dimensions, determined by the extreme points of the front bulldozer blade. The radius of the rear dimensions in this case can be ignored, because it is of negligible importance. If you make a u-turn at an intersection, you can take the grader blade out of the roadway. The maximum radius is determined by the size of the blade that goes beyond the width of the grader.

*Conclusion.* The obtained solutions can be used to determine safe maneuvering modes for motor graders in urban conditions.

***Keywords:*** motor grader, maneuverability, radius of turn, rotatability.

***For citation****:* Deryushev V. V., Kosenko E. E., Kosenko V. V. Evaluation of safety parameters of the motor grader during maneuvering in the street and road network: Safety of Technogenic and Natural Systems. 2020;3: 33‒38. https://doi.org/10.23947/2541-9129-2020-3-33-38

**Introduction.** When operating construction and utility vehicles in urban environments, the key factor in ensuring safety is maneuvering at intersections with different street widths, in driveways of a given shape and size, as well as on limited areas of the support surface. Road safety in these conditions is determined by the maneuverability properties of wheeled vehicles, one of which is motor graders. The work [1] is devoted to the study of the issues of motor grader maneuverability, and the issues of reliability of equipment operation are covered in [2-4]. A lot of research has been devoted to determining the maneuverability properties of wheeled vehicles, and the main results are fixed in the normative technical documentation. However, the calculation formulas given there are obtained, as a rule, for cases of maneuvering on unlimited areas of the support surface and under the condition that the wheels of the rear and front axles move along the same trajectory. In general, these conditions are not met.

**Problem statement.** The main purpose of these studies is to establish safe values of kinematic and geometric parameters for motor graders maneuvering in urban conditions. To achieve this goal, you need to solve the following two tasks:

1. Set all possible options for grader leaving the roadway, related to its location on the roadway, when performing a u-turn, right turn at the intersection of roads (with two-way or one-way traffic), exit (removal of the front

left dimensions) on the oncoming lane, turn (removal of the right dimensions) on the sidewalk, as well as the removal of the rear left dimensions on the adjacent lane.

2. Determine what turning radius a grader with the specified length and width should have when making a right turn at the intersection of roads with the specified width of streets (with two-way or one-way traffic), in order to avoid the above-mentioned situations of the grader leaving the borders of the occupied lane and roadway.

**Materials and methods.** To solve these problems, a calculation scheme is constructed to determine the parameters of the turnability of a grader with an articulated frame (Fig. 1).

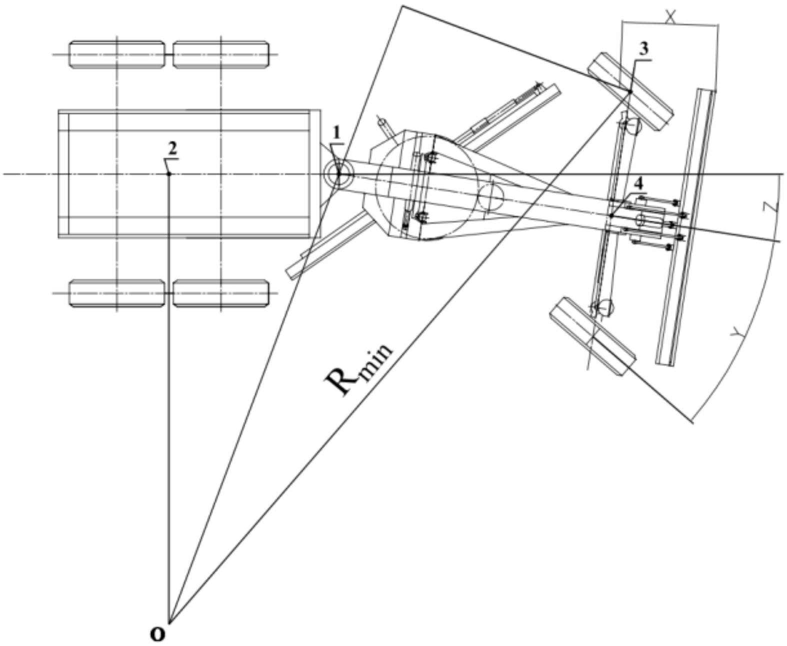


Fig. 1. Calculation model of the motor grader's turnability

In the diagram, point O is the center of rotation (GOST 27257-87 or ISO 7457-83), the point around which the rotation of a constant radius is performed. The center of rotation is determined as the point formed by the intersection of the line 0-2 (perpendicular to the longitudinal axis of the grader, passing through the middle of the rear cart with the driving axles) and the line 0-3 (perpendicular to the plane of rotation of the most remote controlled wheel).

$R_{min}$ — the minimum turning radius (half of the minimum turning diameter according to GOST 27257-87), it is defined as the distance from the center of the turn to the center of contact of the tire with the support surface when the machine performs a steeper turn (i.e., at the maximum angle of the turn of the controlled wheels Y and the articulated frame Z in Fig. 1). Theoretically, $R_{min}$ is determined by the following formula:

$$R_{min} \approx \frac{(1-2)+(1-4)\cdot cosZ}{\sin(Z+Y)}. \quad (1)$$

**Theoretical part.** The example of calculation of turnability parameters. Let the joint divide the base of the grader in the ratio 1/3. Then for the motor grader (I) we get:

segment 1-2 = 2000 mm,
segment 1-4 = 4000 mm,
angle $Z_{max}$ = 22°,
angle $Y_{max}$ = 40°.

$$R_{min} = \frac{2000+4005\cdot cos22°}{\sin(40°+22°)} = \frac{2000+4005\cdot 0{,}927}{0{,}883} = \frac{5708}{0{,}883} = 6470 \text{ mm}. \quad (2)$$

If there is no turn of the articulated frame (angle Z = 0)

$$R_{min} = \frac{6005}{\sin 40°} = \frac{6005}{0{,}643} = 9339 \text{ mm}. \quad (3)$$

To determine the turning radius that a grader should have when making a right or left turn at an intersection with a given width of streets (or roadway), in order to avoid the situation of the grader leaving the lines of streets or roadway, it is necessary to determine the overall traffic corridor. In this case, the overall corridor of $H_г$ movement is determined as the difference between the outer overall turning radius and the inner overall turning radius [5-9].

**Research result. Determination of different turning radii.** Let us determine the overall turning radius (external). This is the distance from the center of the turn to the outermost point of the projection of the machine and its working equipment when performing a turn with a minimum radius (according to GOST 27257-87). Let us denote this radius $R_{гн}$. Under these conditions, it is determined by the right turn of the grader as the left extreme point of the front bulldozer blade, located at X distance from the front axle. .

Then:

$$R_{гн}=R_{min}+X\cdot\sin Z. \qquad (4)$$

In this case, for the motor grader (I):

$$R_{гн}=6470+1240\cdot\sin 22°= 6470+1240\cdot 0,375 = 6935 \text{ mm}. \qquad (5)$$

Let us determine the internal turning radius of the tires (according to GOST 27257-87) or the internal overall radius, which is designated $R_{гв}$.

It is determined by the formula

$$R_{гв} = R_{min}\cdot\cos (Z+Y) + (1\text{-}4)\cdot\sin Z – B. \qquad (6)$$

In this case, for the motor grader (I):

$$R_{гв} = 6470\cdot\cos (40° + 22°) + 4005\cdot\sin 22° – 2500 = 2043 \text{ mm}. \qquad (7)$$

Then the overall traffic lane of the grader ($H_г$) at the maximum sharp turn with the minimum radius is equal to:

$$H_г = R_{гн} – R_{гв} = R_{min} + X\cdot\sin Z – R_{min}\cdot\cos (Z+Y) – (1\text{-}4)\cdot\sin Z+B. \qquad (8)$$

Or after conversions

$$H_г = R_{min} (1 – \cos (Z+Y)) – ((1\text{-}4) –X)\cdot\sin Z + B. \qquad (9)$$

For the motor grader (I):

$$H_г = 6470 (1 – 0,47) – (4005 – 1240)\cdot 0,375 + 2500 = 4892 \text{ mm}. \qquad (10)$$

When making a right or left turn, the overall traffic lane must fit into the specified width of the street for one-way traffic or the permitted traffic lane for two-way traffic, as shown in Fig. 2 [10-11].

In this case, the minimum width of a one-way street (the width of the $S_{пч}$ roadway) is:

$$S_{пч} = R_{гн} – R_{гв} \cdot\cos 45°. \qquad (11)$$

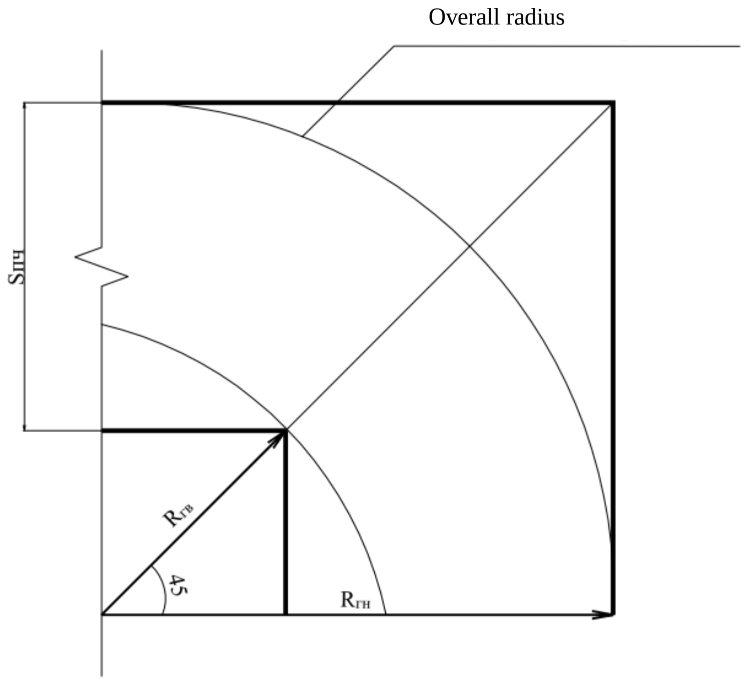


Fig. 2. Internal ($R_{гв}$) and external ($R_{гн}$) overall radii of the motor grader

For the motor grader (I):

$$S_{пч} = 6935 – 2043\cdot 0,707 = 5491 \text{ mm}. \qquad (12)$$

That is, if the width of the street (roadway) $S_{пч}$ is less than 5820 mm (for example, if the specified width is 3 m, 4 m, 5 m), it is theoretically impossible to turn the motor grader (I) without leaving or moving the dimensions outside the permitted lane.

If the roadway width ($S_{пч}$) is set, the required minimum turning radius $R_{min}$ is determined after converting the following expression:

$$S_{пч} = R_{min} + X \cdot \sin Z - (R_{min} \cdot \cos (Z+Y) + (1\text{-}4) \cdot \sin Z - B) \cdot \cos 45. \quad (13)$$

As a result, we get:

$$R_{min} = \frac{S_{пч} + ((1-4) \cdot cos45° - X) \cdot sinZ - B \cdot cos45°}{1 - \cos(Z+Y) \cdot cos45°}. \quad (14)$$

The results of calculations for three types of motor graders are summarized in Tables 1-3.

Table 1

Minimum rotation radius of the motor graider

| | 1-4 | $Z_{max}$ | $Y_{max}$ | $R_{min}$ (mm) | |
|---|---|---|---|---|---|
| | | | | when folded | without folding |
| Grader (I) | 4005 | 22° | 40° | 6470 | 9339 |
| Grader | 4240 | 23° | 40° | 6623 | 9705 |
| Grader | 4320 | 25° | 45° | 6298 | 8939 |

Table 2

Overall radii and minimum street width

| | $R_{гн}$ (mm) | $R_{гв}$(mm) | $H_{г}$(mm) | $S_{пч}$(mm) |
|---|---|---|---|---|
| Grader (I) | 6935 | 2043 | 4892 | 5491 |
| Grader (II) | 7150 | 2134 | 5016 | 5641 |
| Grader (III) | 6868 | 1447 | 5421 | 5845 |

Table 3

Required minimum rotation radii $R_{min}$ (mm)

| Street width | 6 m | 7 m | 8 m | 9 m |
|---|---|---|---|---|
| Grader (I) | 7231 | 8729 | 10226 | 11724 |
| Grader (II) | 7185 | 8658 | 10131 | 11605 |
| Grader (III) | 6507 | 7827 | 9147 | 10466 |

The calculations do not consider the case when the trajectory of the rear and front wheels is the same. In this case, the grader's turnability parameters will be worse.

As a result of the calculations, it was found that the minimum turning radii of the graders are 6470, 6623, 6298 mm, respectively, while the smallest width of the roadway should be 5491, 5641, 5845 mm. $R_{min}$ can be reduced by 10% to guarantee the grader passage.

**Conclusion.** After analyzing the possible options of going beyond the boundaries of the roadway of the grader associated with its location on the roadway for turn, right turn at the crossroads (with one-way or two-way movement), moving (take-out front left dimensions) into the oncoming lane, hitting (the removal of the right dimensions), etc., experts say that a turn of the grader is carried out with all the wheels on the roadway. In this case, the removal of the front dimensions is most likely, determined by the extreme points of the front bulldozer blade. The value of the dangerous radius is Xsin Z (465, 528, 571 mm). The removal of the rear dimensions in this case can not be taken into account, because it is of negligible importance. If you make a sharp turn at an intersection, the grader blade can be removed from the roadway (Fig. 2). The maximum removal is determined by the size of the blade that goes beyond the width of the grader. Thus, the tasks set in this paper are solved, and the obtained analytical expressions can be used in the analysis of the safety of maneuvering of wheeled vehicles in urban conditions.

**References**

1. Portnova A.A. Obosnovanie kriteriya effektivnosti manevrennosti avtogreydera s sharnirno sochlenennoy ramoy [Justification of the maneuverability efficiency criterion for a motor grader with an articulated frame]. Vestnik SibADI. 2014;4(38):34–38. (In Russ.)

2. Kasyanov V.E. et al. Issledovanie ekspluatatsionnoy nadezhnosti avtomobiley pri zamene parametra sdviga raspredeleniya resursa detaley zakona Veybulla [Study of the operational reliability of cars when replacing the parameter of the shift of the resource distribution of parts of the Weibull law]. Kachestvo i zhizn'. 2018;3:65–69. (In Russ.)

3. Kasyanov V.E. et al. Vliyanie general'nykh sovokupnostey konechnogo ob’ema na ekspluatatsionnuyu nadezhnost' avtomobiley pri edinichnom i seriynom proizvodstvakh [Influence of general aggregates of the final volume on the operational reliability of vehicles in single and serial production]. Kachestvo i zhizn'. 2018;3:69–73. (In Russ.)

4. Kasyanov V.E. et al. Preimushchestva primeneniya general'noy sovokupnosti konechnogo ob’ema vmesto vyborki dlya raspredeleniya Veybulla s tremya parametrami [Advantages of using a finite-volume population instead of a sample for a three-parameter Weibull distribution]. Engineering journal of Don. 2018;4:73–87. (In Russ.)

5. Kasyanov V.E., Deryushev V.V., Kosenko E.E., Kosenko V.V., Pshenichnaya A.Yu. Synthesis of methods and principles of ensuring the reliability of one-off and serial production machines. International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2018) electronic edition. Ser. "MATEC Web of Conferences" 2018. p. 02106.

6. Kasyanov V., Deryushev V., Shulkin L., Kosenko E., Kotesova A. Endurance tests of single machines production. International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2018) electronic edition. Ser. "MATEC Web of Conferences" 2018. p. 02107.

7. Demyanov Al.An., Demyanov Al.Al. Metod adaptivnogo sinteza friktsionnykh sistem [Method of adaptive synthesis of friction systems]. Mashinostroenie: entsiklopediya. Podvizhnoy sostav dorog. T. IV, 23; pod. red. B. A. Levina [Mechanical engineering: encyclopedia. Rolling stock of roads-Vol. IV, 23; ed. by B. A. Levin]. Moscow: Mashinostroenie, 2008. p. 72–74. (In Russ.)

8. Demyanov Al.An., Demyanov Al.Al. Adaptivnyy sintez friktsionno-mekhanicheskikh sistem [Adaptive synthesis of friction-mechanical systems]. Problemy i perspektivy razvitiya transportnogo kompleksa: trudy mezhdunar. nauch.-praktich. konf. [Problems and prospects of development of the transport complex: proceedings of the intern. scientific-practical conf.]. Rostov-on-Don, 2009. p. 44–45. (In Russ.)

9. Demyanov Al.An., Demyanov Al.Al. Strukturnyy analiz kak sposob povysheniya nadezhnosti mekhanicheskikh sistem [Structural analysis as a way to improve the reliability of mechanical systems]. Innovatsionnye tekhnologii v mashinostroenii i metallurgii: Mezhdunar. nauch.-prakt. konf. [Innovative technologies in mechanical engineering and metallurgy: Intern. scientific-practical conf.]. Rostov-on-Don, 2011. p. 304–305. (In Russ.)

10. Demyanov Al.An., Demyanov Al.Al. Nekotorye aspekty povysheniya ekonomicheskoy effektivnosti transportnoy infrastruktury [Some aspects of improving the economic efficiency of transport infrastructure]. Problemy mashinovedeniya. Tribologiya — mashinostroeniyu: materialy mezhdunar. nauch.-tekhnich. konf. [Problems of machine science. Tribology — engineering: proceedings of the international scientific and technical conf.]. Moscow, 2012. p. 212–216. (In Russ.)

11. Demyanov Al.An., Demyanov Al.Al. Sintez mekhanicheskikh sistem s podvizhnym osnovaniem [Synthesis of mechanical systems with a movable base]. Transport-2014: trudy mezhdunarodnoy nauch.-praktich. konf. Ch. 1. [Transport-2014: proceedings of the international scientific and practical conference. Part 1.]. Rostov-on-Don, 2014. p. 299–301. (In Russ.)

Submitted 15.05.2020
Scheduled in the issue 01.07.2020

*Authors:*

**Deryushev, Viktor. V.,** Professor, Department of Transport Systems Operation and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sci., Professor, ORCID: http://orcid.org/0000-0003-1812-2834, derushevww@yandex.ru

**Kosenko, Evgeny. E.,** Associate professor, Department of Transport Systems Operation and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate professor, ORCID: https://orcid.org/0000-0003-0515-9849, a123lok@mail.ru

**Kosenko, Vera. V.,** Associate professor, Department of Transport Systems Operation and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate professor, ORCID: https://orcid.org/0000-0002-3312-2771, kosenko_verav@mail.ru

*Contribution of the authors:*

V. V. Deryushev — main concept formulation, goals and objectives of the research; E. E. Kosenko — calculations, preparation of the text, conclusions; V. V. Kosenko — research results analysis, text refinement, correction of the conclusions.