Optimizing the number of anti-skid device for vehicle

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Abstract. We can image the shift work of the vehicle in the form of: a) the movement of the unit from the park to the object of work; b) work on the object; c) the movement from the object to the park. Depending on the condition of the roads, as well as the weather conditions of spring and autumn, the driving wheels of the vehicle can be equipped with the hooks just before leaving, on the road or directly at the work site. In any case, it is necessary to spend a certain amount of the shift time for installation and disassembly of the anti-skid device.

1. Introduction
The characteristics of the undercarriage systems of transport vehicles significantly affect the technical level. The advantages of wheeled propulsion units are obvious compared to crawlers. They are distinguished by their low specific metal consumption and the possibility of using them on highways. Wheeled vehicles provide the best working conditions for the driver and service personnel.

Fundamentals of the wheels rolling theory were laid in the works of such scientists as M. G. Bekker [3], I. P. Ksenevich [4], M. M. Makhmutov [5, 6], N.K. Mazitov [9], R. L. Sakhapov [7, 8] and others. Their works note that the towing properties of vehicles are enhanced by:
1) the use of the entire mass of the tractor;
2) an increase in tire contact with the soil;
3) the development of new design solutions;
4) the development of new technological solutions.

The solution to this issue will be reduced to the determination of such number of anti-skid devices, which will ensure the maximum performance of the vehicle in these operating conditions [2, 3].

Let’s present the shift performance of a vehicle operating without devices, as

\[ W_{III} = 0.36 T_O B V_T \left(1 - \delta_{III}\right) \] (1)

Then the shift performance of the vehicle working with devices will be determined as:

\[ W_C = 0.36 \left(T_O - z_C T_C\right) B V_T \left(1 - \delta_K\right) \] (2)

where \( V_T \) – theoretical speed, m/s; \( T_O \) – basic working time, hrs; \( B \) – vehicle width, m; \( T_C \) – time required for installation and disassembly of the anti-skid device, hrs.

Consequently, the change in shift performance will be:
\[ \Delta W_{CM} = 0.36 B V_T \left[ T_O \left( \delta_{III} - \delta_K \right) - z_c T_c \left( 1 - \delta_K \right) \right] \]  \quad (3)

With the increase in the number of anti-skid devices on the driving wheel, the expression in square brackets of the optimization model changes, having an extremum point [4].

For the full slip mode of the propulsor, equipped with removable hooks, the model of their quantity optimization, according to the increment factor of the shift time, will receive the following form:

\[ \Delta T = \left( 1 - \delta_K \right) \cdot \left( T_O - z_c T_c \right) \]  \quad (4)

For general case we have:

\[ \Delta T = T_O \left( \delta_{III} - \delta_K \right) - z_c T_c \cdot \left( 1 - \delta_K \right) \]  \quad (5)

The resulting model of optimization of the number of antiskid devices graphically represents a curve with an extreme value (Figure 1).

2. Materials and methods
The results of the study showed that diamond-shaped intersections at two levels are the safest intersection types. First, the diamond-shaped intersection is simple in layout and provides good visibility for drivers, which greatly reduces the likelihood that the driver can choose the wrong direction to enter or exit. Second, the ramps of the diamond-shaped intersection at different levels have a direct form. Curvy ramps have a higher degree of risk than direct ones. Third, in most cases at the diamond-shaped intersections a minor road passes over the main road.

The research plan includes:
- development of experimental research methods in accordance with GOST 7057-2001;
- the choice of objects and places for experimental studies in accordance with GOST 20915-75;
- determination of research plans and the optimal limits of change of the considered factors based on GOST 24026-80;
- preparation of tools for operation, and determination of their measurement errors;
• conduction of experimental studies and registration of measured factors (parameters) in accordance with GOST 30745-2001, GOST 3481-79;
• preparation and processing of the obtained experimental material in accordance with GOST 8.207-76.

Figure 2 shows the purpose, objectives of research and ways to achieve them.

3. Discussion
With the rising number of hooks, we observe an increase in the shift time to a certain value, after which it starts to decrease. The maximum value of the increment in these operating conditions of the unit will determine the optimal number of devices on the wheel [7].

In order to get the mathematical model of the optimal number of anti-skid devices on the propulsor from the expression (2), we take the derivative by equating it to zero and substituting the model (3), we get:
\[
\Delta T' = \left( T_o \delta_{\text{III}} - T_o \delta_{\text{III}} + T_o z_c (\delta_{\text{III}} - \delta_{\text{CIII}}) \times \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} - z_c T_c + z_c T_c \delta_{\text{III}} - z_c^2 T_c (\delta_{\text{III}} - \delta_{\text{CIII}}) \times \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} \right).
\]

Consequently,
\[
T_o \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} - T_c + T_c \delta_{\text{III}} - 2 z_{\text{opt}} T_c \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} = 0
\]
\[
z_{\text{opt}} T_c \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{90} = T_o \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} - T_c + T_c \delta_{\text{III}}.
\]

From here we find \( z_{\text{opt}} \):
\[
z_{\text{opt}} = \frac{90 \cdot T_o \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} - T_c \cdot (\delta_{\text{III}} - 1)}{\arccos \left( \frac{R_k}{R_k - h_c} \right)}.
\]

Therefore, after the transformations we get:
\[
z_{\text{opt}} = \frac{0.5 \cdot T_o \cdot (\delta_{\text{III}} - \delta_{\text{CIII}}) \cdot \frac{\arccos \left( \frac{R_k}{R_k - h_c} \right)}{180} - 90 \cdot T_c \cdot (1 - \delta_{\text{III}})}{\arccos \left( \frac{R_k}{R_k - h_c} \right)}.
\]

Analysis of this model shows that the optimal number of anti-skid devices is influenced by the vehicle’s basic operation time, device installation and disassembly time, slip coefficients of the wheel with and without hooks [8].

Let’s determine the optimal number of hooks on the propulsor for the next levels and intervals of variation of significant factors (Table 1).
Table 1. Levels and factors of interval variation.

| Levels | Sign | Factors |
|--------|------|---------|
| Lower  | -1   | 5, 1   |
| Central| 0    | 16, 0  |
| Upper  | +1   | 7, 0  |
| Variation Interval | $\Delta X$ | 1, 0 |
| $T_{o}, h$ | $T_{c}, h$ | $\delta_{III}$ | $\delta_{K}$ |
| 0,1    | 0,2  | 0,3    | 0,15  | 0,30  | 0,45  | 0,05  | 0,10  |
| 5      | 5,4  | 1,2    | -21,9 | 5,4   | 9,3   | 6,8   | 5,4   | 3,0   |
| 6      | 22,9 | 7,9    | 2,9   | -19,4 | 7,9   | 11,8  | 9,3   | 7,9   | 5,5   |
| 7      | 27,9 | 10,4   | 4,6   | -16,9 | 10,4  | 14,3  | 11,8  | 10,4  | 8,0   |

4. Results

The calculated values of the optimal number of hooks on the propulsor according to model (5) showed the following values (Table 2).

Table 2. Calculated values of the optimal number of anti-skid devices according to the criterion of traction properties.

| $T_{o}, h$ | $T_{c}, h$ | $\delta_{III}$ | $\delta_{K}$ |
|------------|------------|----------------|--------------|
| 5          | 6          | 7              | 0,15         |
| 0,1        | 17,9       | 22,9           | 27,9         |
| 0,2        | 5,4        | 7,9            | 10,4         |
| 0,3        | 1,2        | 2,9            | 4,6          |

With an increase in the basic operating time of the vehicle, regardless of the time of installation and disassembly, the optimal number of hooks increases at a central level of variation of the factors in a linear relationship. At $T_{c} = 0.1$ hrs, the increase in maintenance by 1 hour increases $Z_{opt}$ by 5 pcs., At $T_{c} = 0.2$ hrs - by 2.5 pcs., At $T_{c} = 0.3$ hrs - by 1.7 pcs.

With an increase in the basic operating time of the vehicle, regardless of the size of wheel slip, the optimal number of hooks increases at a central level of variation of the factors in a linear relationship. However, when $\delta_{III} = 0.15$, $Z_{opt}$ has negative values, which means that it is inexpedient to use hooks in these operating conditions. At $\delta_{III} = 0.30 ... 0.45$ increase in $T_{o}$ for 1 hour, increases $Z_{opt}$ by 2.5 pcs.
With an increase in the basic operating time of the vehicle at the central level of factors variation, regardless of the wheel slip value $\delta^K$, the optimal number of hooks increases in a linear relationship and the increase in maintenance $T_O$ for 1 hour increases $Z_{opt}$ by 2.5 pcs.

After studying the effect of installation and disassembly time of the anti-skid device on the optimal number of hooks, we should note that regardless of the basic operating time of the vehicle, with an increase in $T_C$, $Z_{opt}$ decreases along the curve with negative acceleration (Figure 3). At the central level of factors variation, with an increase in $T_C$ in the range of 0.1 ... 0.2 hrs, $Z_{opt}$ decreases by 34.5%, for $T_O = 5$ hours - by 30.2%, for $T_O = 7$ hours - by 37.2%. For the range of $T_C$ 0.2 ... 0.3 hrs, $Z_{opt}$ is reduced by 22.2; 36.7 and 44.2% respectively.

With an increase in the time of installation and disassembly of the device at the central level of factors variation, regardless of the value of the wheel slip $\delta^W$, the optimal number of hooks decreases along the curve with a negative acceleration. However, when $\delta^W = 0.15$, $Z_{opt}$ has negative values, which means that it is inexpedient to use hooks in these operating conditions. At $\delta^W = 0.30 ... 0.45$, the increase in the vehicle in the range from 0.1 ... 0.2 hours reduces $Z_{opt}$ by 15 pcs., and in the $T_C$ range from 0.2 ... 0.3 hrs to 5 pcs.

**Figure 3.** Change of the optimal number of anti-skid devices from the time of installation and disassembly of the device and the basic operating time of the vehicle:

1 – $T_O = 5$ hrs; 2 – $T_O = 6$ hrs; 3 – $T_O = 7$ hrs.
Figure 4. The influence of the installation and disassembly time of the device and wheel slip factor $\delta_K$ on the optimal number of the hooks:

$1 - \delta_K = 0.05; 2 - \delta_K = 0.10; 3 - \delta_K = 0.15.$

With an increase in the disassembly time of the device, at the central level of factors variation, regardless of the wheel slip value $\delta_K$, the optimal number of hooks decreases along the curve with negative acceleration (Figure 4). At $\delta_K = 0.05 \ldots 0.15$ with an increase in the $T_C$ in the range from 0.1 ... 0.2 hours, $Z_{opt}$ is reduced by 15 pcs., And in the $T_C$ range from 0.2 ... 0.3 hours - by 5 pcs.

After studying the influence of wheel slip on the optimal number of hooks, we should note that at the central level of factors variation at $T_O = 5$ hours, it is inexpedient to equip the vehicle with hooks. For $T_O$ at 6 ... 7 hours, the expediency of equipment arises at high values of propulsor slipping and with an increase of $\delta_{\omega}$ in the range of 0.30 ... 0.45 $Z_{opt}$ increases by 4 pcs.

With an increase in wheel slippage at a central level of factors variation, regardless of the time of installation and disassembly of the device, the optimal number of hooks increases along a curve with a negative acceleration (Figure 5). However, at low values of $\delta_{\omega} = 0.15$, it is inexpedient to equip the vehicle with hooks. With an increase of $\delta_{\omega}$ in the range 0.30 ... 0.45 at $T_C = 0.1$ h, $Z_{opt}$ increases by 1.2 times, at $T_C = 0.2$ hours - 1.5 times, and at $T_C = 0.3$ hours - in 2.3 times.

With an increase in wheel slip, at a central level of factors variation, regardless of the value of wheel slip, equipped with hooks $\delta_K$, the optimum number of hooks decreases along a curve with negative acceleration (Figure 5). At $\delta_K = 0.05$ with an increase of $\delta_{\omega}$ in the range 0.30 ... 0.45, $Z_{opt}$ is increases by 3 pcs., for $\delta_K = 0.10$ - by 4 pcs., for $\delta_K = 0.15$ - by 5 pcs.

After studying the influence of the slip of the equipped wheel $\delta_K$ on the optimal number of hooks, we should note that at the central level of factors variation at $T_O = 5$ hours, with an increase of $\delta_K$ in the range from 0.05 to 0.10, $Z_{opt}$ decreases by 20.5%; at $T_O = 6$ h - by 15.1%; at $T_O = 7$ h - by 11.9%.

With an increase of $\delta_K$ in the range from 0.10 to 0.15, $Z_{opt}$ decreases by 44.4; 30.7% and 23.1% respectively. With an increase of $\delta_K$ in the range from 0.05 to 0.10, depending on the time of
installation and disassembly of the device, \( Z_{\text{opt}} \) decreases in a linear relationship and equals to 2 pcs on average.

With wheel slippage value \( \delta_{\text{III}} = 0.15 \), at the central levels of factors variation, \( Z_{\text{opt}} \) has negative values, therefore, it is not advisable to equip the propulsor with removable hooks in these operating conditions. With an increase of \( \delta_{K} \) in the range from 0.05 to 0.10, with \( \delta_{\text{III}} = 0.30 \), \( Z_{\text{opt}} \) decreases by 15.1%; for \( \delta_{\text{III}} = 0.45 \) - by 3.2%. With an increase of \( \delta_{K} \) in the range from 0.15 to 0.10, \( Z_{\text{opt}} \) decreases by 30.3 and 4.2%, respectively.

One of the factors that increase the productivity of the vehicles (as shown by the models [8]) and, consequently, the range of expediency of removable hooks usage, is the time required for installation and disassembly of the anti-skid device [9]. The value of this factor depends on the mass of the removable device, convenience and the connection of its attachment to the wheel rim.

We have developed and manufactured prototypes of removable anti-skid devices with minimal attachment on the wheel rim.

![Figure 5](image_url)

**Figure 5.** Influence of slipping coefficient \( \delta_{\text{III}} \) on the optimal number of anti-skid devices depending on the time of installation and disassembly of the device: 1 \(- T_C = 0.1 \text{ hrs}; 2 - T_C = 0.2 \text{ hrs}; 3 - T_C = 0.3 \text{ hrs.} \)**

![Figure 6](image_url)

**Figure 6.** Change the optimal number of anti-skid devices from \( \delta_{\text{III}} \) and \( \delta_{K} \): 1 \(- \delta_{K} = 0.05; 2 - \delta_{K} = 0.10; 3 - \delta_{K} = 0.15. \)**
The anti-skid device for traction class 0.9 ... 2.0 consists (Figure 7) from the axis 1, fastened to the wheel rim disk by nuts 3 and fixing the position of the cheek 2, the guide sleeve 4, with the bolt 5, the adjustable stand 6 with the holes 10; hook 7, fixed in the lower groove of the rack using a bolt connection 8, and spring 9.

A device for wheel propulsors consists of a bracket 1 (Figure 7), a pillar 2 fixed to the bracket with the help of bolts 3; a hook 4 connected to the bottom of the rack by a bolt connection 5. To increase the resistance of the bracket, stiffener 6 is welded to bending and torsion moments.

5. Conclusion
Mitigation of dynamic loads on the wheel disk is achieved by a rubber gasket 7, worn on one of the edges of the bracket.

To attach the device to the wheel rim, it is enough to unscrew one of the disc nuts and, aligning it with the hole in the bracket, fix the device. On average, the installation and disassembly of the device takes 8 ... 12 minutes.

Thus, this analysis of the model for optimizing the number of removable hooks, depending on the operating time of the vehicle, installation and disassembly of the anti-skid device, soil properties by the criterion of traction characteristics of the propulsor, shows its suitability in engineering calculations.

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