Influence of the charging pressure of the hydraulic pneumatic accumulator of the communal machine control device on the pressure force of the brushed working body

S I Tsekhosh¹, S D Ignatov¹, VS Shcherbakov¹ and I N Kvasov²
¹Siberian Automobile and Highway University, Mira Ave., 5, Omsk, Russia
²Omsk State Technical University, 11, Mira Ave., Omsk, 644050, Russia

Abstract. The article is devoted to the actual problem of increasing the efficiency of cleaning the roadway with a communal machine. To increase the cleaning efficiency, it is necessary to provide the required pressing force and thus the required area of the contact spot between the brush pile and the surface to be cleaned, which can be done by using a position control device for the brush working equipment.

Research methods. In the process of research were used the following methods: analysis, synthesis, ascent from the abstract to the concrete. The results of the study of the influence of the parameters of the control device on the criterion of the efficiency of the working process of the communal machine are presented.

Results. As a result of the analysis of the process of interaction of the brush working equipment with the surface being cleaned, the dependences connecting the standard deviation of the pressing force of the brush working equipment to the surface to be cleaned from the required value, taking into account the wear of the pile and the charging pressure of the hydraulic pneumatic accumulator, were revealed, their approximation was carried out, and the regression equation was obtained.

Conclusions. The studies carried out made it possible to obtain regression equations which are used to determine the optimal value of the standard deviation of the pressing force from the required one for different degrees of wear of the pile, depending on the charging pressure of the hydraulic pneumatic accumulator. The research results can be applied in the design of automatic control systems for the position of the working bodies of construction and road machines.

Keywords: communal machine, hydraulic pneumatic accumulator, brush working equipment, charging pressure, pile deformation.

1. Introduction

In the process of cleaning work, the movement of municipal equipment along the cleaned roadway is carried out under the influence of the external environment (for example, surface irregularities), which reduces the productivity of the working process (WP). These irregularities are one of the main reasons for arbitrary impact on the elements of the running equipment of the machine. These amplitude characteristics and acceleration can reach large values. This has an impact on the performance of the communal machine (CM) and can cause significant economic costs.

Therefore, in order to eliminate this negative impact and achieve maximum performance from cleaning the roadway, it is necessary to ensure the required value of the pressing force of the brush working body (BWB) to the surface to be cleaned, taking into account the type of pile, the degree of wear and the material from which it is made [1, 2]. This can be achieved by using a control device (CD) for the position of the BWB (brushed working body), one of the main elements of which is the hydro-pneumatic accumulator (HNA), which provides the pressing force of the BWB.

As a criterion for assessing the effectiveness of the WP of the CM, it is proposed to consider the standard deviation of the pressing force of the BWB from the required value ($\sigma_{F_p}$). This criterion depends on the parameters of the control unit by the position of the BWB and, first of all, on the charging pressure of the HNA ($P_{ch}$). The developed control unit allows to provide such a value of the vertical coordinate of the BWB, proportional to the vertical coordinate of the roadbed, which corresponds to the required value of the...
pressing force of the BWB, the required area of the contact patch and, as a result, to increase the productivity of the WP of the CM [5].

The purpose of this article is to determine the functional relationship between the standard deviation of the pressing force of the BWB and the charging pressure of the hydraulic pneumatic accumulator.

2. Formulation of the problem
Research objectives are:
1. Determine the type of the objective function, reflecting the effectiveness of the WP of the CM.
2. To analyze the simulation models of the WP of the CM before and after the modernization of the control system.
3. Reveal the relationship between the HNA charging pressure and the efficiency criterion of the WP of the CM.
4. Implement the approximation of the results of a machine experiment, draw up a regression equation.

3. Theory
Based upon the foregoing, the following conclusion has been drawn:
1. The target function, indicating the effectiveness of the working process (WP) of the communal machine (CM) can be:

\[ \sigma_{F_{pr}}(P_{ch}) \to 0, \]

where \( \sigma_{F_{pr}} \) is the standard deviation of the pressing force of the BWB from the required value, H; \( P_{ch} \) - pressure of charging the HNA, MPa.

Boundary values of the objective function parameters are:

\[ P_{ch\ min} \leq P_{ch} \leq P_{ch\ max} \]

(2)

2. An increase in the efficiency of the WP of the CM equipped with a BWB is possible due to the determination of the optimal value of the charging pressure of the HNA \( P_{ch} \), at which the required value of the objective function is provided.

The results of the research made it possible to develop simulation models, with the help of which the analysis of the WP of the CM before and after the modernization of the control system was carried out. The sources of uncontrollable distortions of the values of the pressing force of the BWB in relation to the processing surface are also determined [6].

For simulation models, the initial disturbing vibrations are the impacts from the unevenness of the surface being cleaned on the elements of the running equipment and CM road wheels [3]. The described effects are the cause of uncontrollable changes in the pressing force \( (F_{pr}) \) of the BWB to the surface being cleaned [4].

At the output of the model, the force of pressing the BWB to the cleaned surface is formed.

In the course of the work to determine the levels of influence of external factors on the working process, it was decided to distinguish three groups of model parameters:
1. Fixed group, taking into account: the design features of the communal machine and the BWB; the dependence of the roadbed and the BWB; depreciation of working equipment elements and their rigidity; speed of movement of the CM and volume of HNA.
2. Variable group.
3. Random group - caused by irregularities in the microrelief.

The studies consisted in the analysis of the dependence of the effectiveness of the WP of the CM on the variable parameter, which was estimated on the basis of the proposed criterion of effectiveness (1).

4. Results of the experiments and discussion
Currently, almost all CMs equipped with a cylindrical brush use support rollers to adjust the contact patch of the brush bristle with the surface being cleaned. This method is simple in its implementation, but has low efficiency, since, due to the design features of the support rollers fastening, the dimensions of the contact patch of the pile with the cleaned surface change during the WP. As a result of the analysis of the simulation model of the WP of the CM with road wheels. Irregularities of the microrelief are formed at different speeds of the CM movement. Figure 1 shows, as an example, the changes in the vertical coordinates of the microrelief irregularities and the displacement of the BWB.

Figure 1. Change of vertical coordinates of microrelief irregularities (-) and the brush working body (BWB) (-) of the communal machine

Figure 2 shows that the process of deformation of the pile and, consequently, the size of the contact spot of the BWB with the surface to be cleaned are random. Moreover, at some points in time, there is no contact of the BWB with the surface being cleaned, which negatively affects the cleaning efficiency.

Figure 2. Time dependence of the deformation of the pile (a) and the pressing force of the brush working equipment (BWE) to the surface to be cleaned (b)
On time intervals, for example $t = 50-60$ seconds, the separation of the BWB from the surface to be cleaned occurs, as a result of which a decrease in the pressing force to zero is observed.

In other areas, where the BWB coordinate is less than the vertical coordinate of the surface to be cleaned, for example 60-70 seconds, a sharp increase in the pressing force is observed. Taking into account the fact that the required value of the pressing force for a particular brush under consideration is $F_{pr} = 1427$ H, the standard deviation ($\sigma_{Fpr}$) of the pressing force of the BWB to the cleaned surface from the required value in this case is $\sigma_{Fpr} = 1080.57$ H.

The results obtained indicate the need to equip the CM with a device for controlling the position of the brush working body (CD), which will make it possible to abandon the road wheels and reduce the $\sigma_{Fpr}$.

Analysis of the results of simulation of the working process of a communal machine equipped with a device for controlling the position of the brush working body

Research has been carried out on the simulation model of the WP of the CM, equipped with the control unit with the position of the BWB, the time dependences of the vertical coordinates of the BWB on the value of $P_{ch}$ are established for different wear of the pile of the BWB.

Investigations of the WP of the CM were carried out using a BWB with a new pile and with a pile wear of 22% and 43%. The HNA was selected taking into account the volume of the rod cavity of the executive hydraulic cylinder. The studies were carried out at $V_{HNA} = 12$ l and $v_{km} = 6$ km/h.

As a result of the analysis of the simulation model of the WP of the CM with a control unit and a new brush, the following results were obtained.

Figure 3. Change of the vertical coordinates of the microrelief irregularities (-) and a brush working body (BWB) (-) of a communal machine ($P_{ch} = 0.06$ MPa)

Figure 3 shows that the deformation of the pile and, consequently, the size of the contact spot of the BWB with the surface being cleaned are practically the same. There is a constant contact of the BWB with the surface being cleaned.
Figure 4. Time trend of changes in the deformation of the pile of a communal machine with a control device ($P_{ch} = 0.06$ MPa) (a) and the pressing force of the BWB to the surface being cleaned (b)

From the results of the relationship shown in the graphs above, we can observe that, for the required value, the standard deviation of the pressing force of the BWB to the surface to be cleaned is $\sigma_{Fpr} = 123.8$ N. This suggests that the introduction of the CD position of the BWB allows providing an almost constant pressing force of the BWB to the surface to be cleaned and, as a consequence, stabilize the contact spot. This helps to increase the efficiency of cleaning the roadway and reduce the wear of the BWB pile.

In the course of the study, taking into account the new pile, the $P_{ch}$ values varied from 0.06 MPa to 0.1 MPa. The results of the study of the WP of the CM, equipped with the CD position of the BWB, at various values of $P_{ch}$ and a new pile are summarized in table 1.

Table 1. Research results for the new pile

| $P_{ch}$ - MPa | 0.06 | 0.066 | 0.07 | 0.072 | 0.077 | 0.08 |
|----------------|------|-------|------|-------|-------|------|
| $\sigma_{Fpr}$ - H | 123.8 | 52.9  | 46.7 | 68.34 | 118  | 140  |

According to the tabular data, the graphical dependence $\sigma_{Fpr} = f(P_{ch})$.

Figure 5. A graph of the dependence of the standard deviation of the pressing force from the charging pressure of the hydraulic pneumatic accumulator

As a result of approximating the graph by a second-order polynomial, the regression equation is obtained

$$\sigma_{Fpr}(P_{ch}) = 819173 \cdot P_{ch}^2 - 112924 \cdot P_{ch}^2 + 3944.5,$$  \hspace{1cm} (3)
where $\sigma_{Fpr}$ is the standard deviation of the pressing force BWB, H; $P_{ch}$ - pressure of the HNA charging, MPa.

The coefficient of determination was $R^2 = 0.9159$.

The force of pressing the BWB to the surface to be cleaned depends on the wear of the pile. At 22% wear, it should have a value of 2249 H, and for 43% wear, a value of 3894 H.

In the course of the study, taking into account the wear of the pile of 22%, the values of $P_{ch}$ varied from 0.035 MPa to 0.065 MPa.

The results of the study of the WP of the CM equipped with the control unit with the BWB position, at various values of the HNA charging pressure and 22% pile wear are summarized in Table 2.

**Table 2.** Research results for the 22% weared pile

| $P_{ch}$ (MPa) | 0.035 | 0.04 | 0.045 | 0.05 | 0.055 | 0.06 | 0.065 |
|----------------|-------|------|-------|------|-------|------|------|
| $\sigma_{Fpr}$ (H) | 280.5 | 209.8 | 125.69 | 80.405 | 95.65 | 181.24 | 259.1 |

According to the tabular data, a graphical dependence $\sigma_{Fpr} = f(P_{ch})$ is built (Fig. 6).

![Graph of the dependence of the standard deviation of the force pressing from the required value and charging pressure of the hydraulic pneumatic accumulator](image)

**Figure 6.** The graph of the dependence of the standard deviation of the force pressing from the required value and charging pressure of the hydraulic pneumatic accumulator

As a result of approximation of the graphical dependence by a second-order polynomial, the regression equation is obtained:

$$\sigma_{Fpr}(P_{ch}) = 815410 \cdot P_{ch}^2 - 82622 \cdot P_{ch} + 2187.1.$$  \hspace{1cm} (4)

The coefficient of determination is $R^2 = 0.9624$.

During the study, taking into account the wear of the pile of 43%, the values of $P_{ch}$ varied from 0.021 MPa to 0.029 MPa.

The results of the study of the WP of the CM, equipped with the control unit of the position of the BWB, at various values of the charging pressure of the HNA and the wear of the pile 43% are summarized in Table 3.

**Table 3.** Research results for the pile wear 43%

| $P_{ch}$ (MPa) | 0.021 | 0.022 | 0.023 | 0.024 | 0.025 | 0.026 | 0.027 | 0.028 | 0.029 |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $\sigma_{Fpr}$ (H) | 150.6 | 120.5 | 90.4 | 60.3 | 30.2 | 0.1 | 0.2 | 0.3 | 0.4 |

During the study, taking into account the wear of the pile of 43%, the values of $P_{ch}$ varied from 0.021 MPa to 0.029 MPa.

The results of the study of the WP of the CM, equipped with the control unit of the position of the BWB, at various values of the charging pressure of the HNA and the wear of the pile 43% are summarized in Table 3.
According to the tabular data, the graphical dependence $\sigma_{F_{pr}} = f(P_{ch})$ was built (Fig. 7).

![Graph](image)

**Figure 7.** A graph of the dependence of the standard deviation of the pressing force from the required value and the charging pressure of the hydraulic pneumatic accumulator.

As a result of approximating the graph by a second-order polynomial, the regression equation is obtained:

$$
\sigma_{F_{pr}}(P_{ch}) = 5 \cdot 10^6 \cdot P_{ch}^2 - 232511 \cdot P_{ch} + 3285.3.
$$

The coefficient of determination is $R^2 = 0.9115$.

5. The discussion of the results
Dependences (3-5), taking into account the objective function (1), make it possible to determine the optimal values of the charging pressure, taking into account the wear of the pile.

6. Resumes and conclusions
Approximation of the simulation results made it possible to obtain regression equations, which were used to determine the optimal value of the HNA charging pressure, at which the minimum value of the root-mean-square deviation of the pressing force from the required one is ensured. The obtained dependences made it possible to form an engineering technique for optimizing the CD parameters by the position of the BWB.

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