

Mathematical model of the working process of the road sweeping machine as a complex dynamic system

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Abstract. The article is devoted to the urgent problem of improving the roadway cleaning efficiency. To achieve maximum cleaning efficiency, an optimal pressing force of the brush equipment to the surface being cleaned should be provided. A schematic diagram of a sweeping machine working process as a complex dynamic system was constructed including a basic machine, brush and running equipment, a hydraulic drive, a road surface, as well as a microrelief control device reflecting the effect of the microrelief on the vertical coordinate of the working equipment. A mathematical model of the working process of a sweeping machine is presented. The simulation was carried out using the MATLAB software, Simulink extension. As a result, the dependences of the vertical coordinates and the pressing force of the brush equipment were established. In most cases, the brush positioning control is provided by a standard hydraulic drive; however, when the dimensions of a pothole are large enough, the standard hydraulic pump does not guarantee the required speed of the control device so that the deviations of the vertical coordinate could be compensated. To improve the speed of the brush positioning control device, the standard hydraulic pump was supplemented with an additional pump switching on only at particular periods of time.

Keywords: road sweeping machine, workflow, microrelief, brushwork equipment, control device

1. Introduction

In the cleaning process, the movement of the sweeping machine along the supporting surface occurs under the influence of various external factors affecting the efficiency of the working process, among them are the roughness of the roadway, degree of surface contamination, etc. The roughness of the supporting surface is the main source of uncontrolled oscillations of the machine. The amplitudes and accelerations of these oscillations appear to reach significant values. To achieve the maximum effect of the process of cleaning the surface, the optimum pressing force of the brush working equipment (BWE) to the surface being cleaned should be ensured, considering the type and material of the bristle.

Prior to the beginning of this study, publications in both foreign and Russian scientific journals were analysed [1]. A similar topic was addressed by Zhengdong Z. et al. in the scientific journal "Modelling and simulation" in the article "Simulation Analysis of Rolling Brush Performance of



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Towed Road Sweeper Based on ADAMS" [2], in which the authors analysed the characteristics of the sweeping machine, such as the speed of the brush working equipment and the speed of the sweeping machine. However, researchers did not focus on the dependence between the deformation and the pressing force of the brush working equipment, which could facilitate optimization of the brush pressing force of the sweeping machine to the surface being cleaned.

In this work, taking into account the abovementioned parameters, we carried out calculations and constructed a mathematical model of the working process of a road sweeping machine as a complex dynamic system. A mathematical model of a sweeping machine equipped with a control device for the BWE positioning facilitates determination of optimal values of the parameters of this device. By controlling the vertical coordinate of the BWE, pressing force values will be provided guaranteeing the bristle deformation not exceeding the values required for effective cleaning.

2. Formulation of the problem

To determine the possibility of using the proposed device for controlling the vertical coordinate of the BWE, a mathematical model of the working process of a sweeping machine as a complex dynamic system should be compiled based on a schematic diagram of a working process reflecting connections between different subsystems.

Experimental studies should be conducted on a mathematical model, the results of which will confirm the operability of the proposed control device.

3. Theoretical part

The mathematical model of the interaction of elements of the running equipment with the microrelief of the roadway reflects one of the subsystems of the complex dynamic system of the working process of the sweeping machine [3]. To study the oscillatory processes of the parts of a sweeping machine caused by roughness of the roadbed, the methods of statistical dynamics using stochastic models of the relief of the roadbed were applied [4].

In order to represent the relations between the subsystems of the machine involved in the working process, a schematic diagram of the working process was constructed (see figure 1) [5].

The microrelief has an effect on the running equipment, in particular on the left and right wheels (C_1), causing their vertical movements. The subsystem of running equipment perceives the disturbing effect from the side of the microrelief, in turn, acting on the frame of the machine (C_2) and changing its spatial position. Further, the effect is transmitted to the BWE (C_3), which changes its position in space and, as a result, the pressing force (C_4) of BWE to the road surface changes. Depending on the type of road surface and BWE parameters, road surface (C_5) affects the bristle deformation, which in turn changes the pressure in one of the hydraulic drive lines (C_6).

Using sensors, the control device determines the pressure change (C_7) in the hydraulic line, compares its value with the required one, which corresponds to the optimal pressing force, and generates a control action (C_8) on the electric hydraulic control valve. The lifting-lowering hydraulic cylinder changes the vertical BWE coordinate (C_9), thereby providing the optimal force of pressing the bristle (C_4).

The presented schematic diagram of the working process of a sweeping machine equipped with BWE serves as the basis for the development of a mathematical model in the Matlab software product, used in further studies [6, 7].

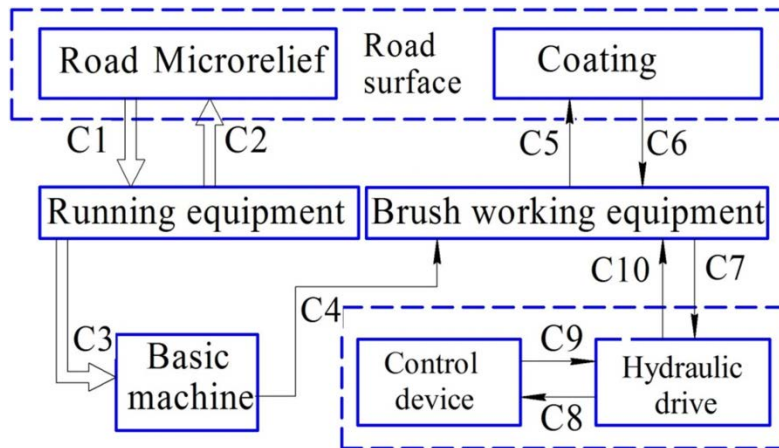


Figure 1. Schematic diagram of a sweeping machine working process as a complex dynamic system.

As a result of the composition of the individual subsystems, a mathematical model of the working process of a sweeping machine was compiled (see figure 2) [8]. The developed mathematical model provides the analysis of the working process of a sweeping machine and establishment of the reasons for the uncontrolled change in the BWE pressing force to the surface being cleaned [9, 10].

The input parameters of the mathematical model involve the disturbing effects on the running equipment from the microrelief of the roadway (Microrel-prav, Microrel-lev). The output parameter is the pressing force of the BWE to the surface being cleaned (F).

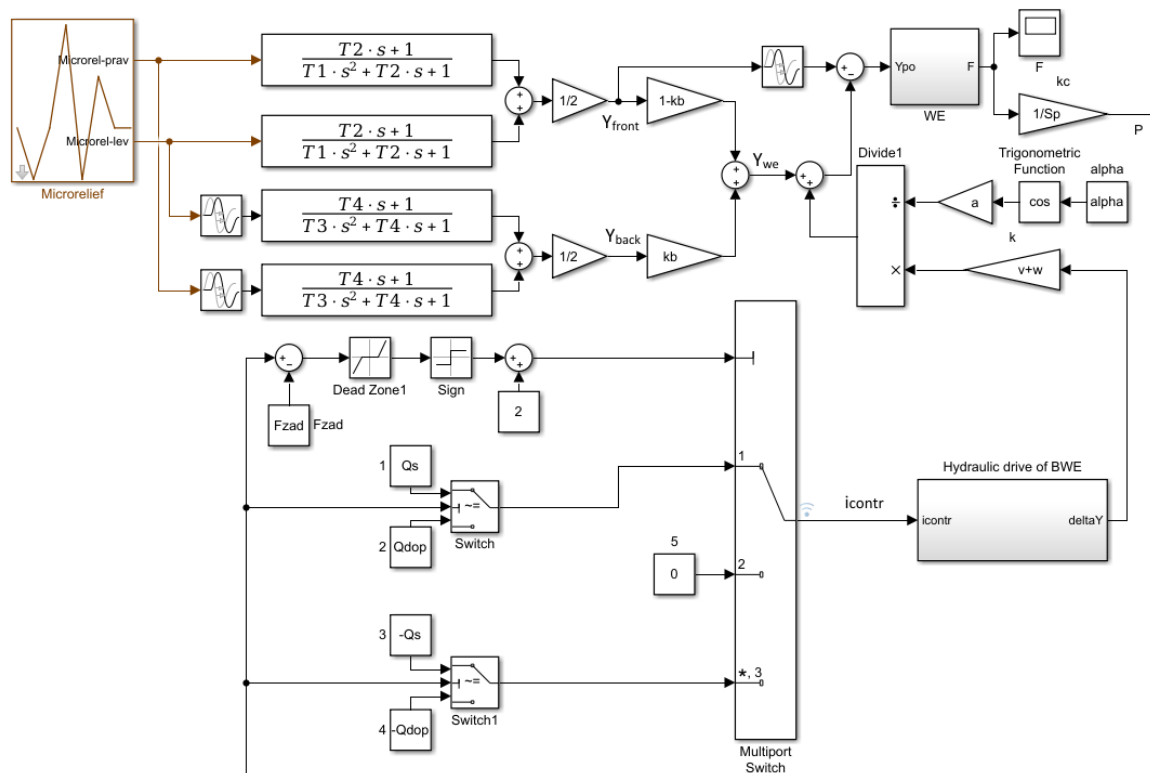


Figure 2. Mathematical model of the working process of a sweeping machine equipped with a device for controlling the brush pressing force to the surface to be cleaned.

The developed mathematical model made it possible to carry out theoretical studies of the working process of a sweeping machine both with and without a vertical coordinate control device [11, 12].

One of the tasks of theoretical studies of the mathematical model of the working process of a sweeping machine was to determine the values of the parameters of hydraulic pumps [2, 13].

Before conducting research, the model parameters were divided into three groups:

1. Fixed parameters
2. Stochastic parameters
3. Variable parameters

This separation helped us to determine the degree of influence of various parameters on the efficiency of the work process.

Fixed parameters include:

- 1) The geometric dimensions of the sweeping machine and the BWE
- 2) The trend of the reaction force of the roadway to the BWE
- 3) Rigidity and dissipation of elements of running equipment
- 4) Masses of machine parts
- 5) The speed of the sweeping machine
- 6) The "dead zone" width of the vertical coordinate control device of the BWE

Stochastic parameters include:

- 1) Microrelief parameters

Variable parameters include:

- 1) Displacements of regular and additional hydraulic pumps

Further research comes down to an analysis of the influence of the parameters of the control device for the position of the BWE on the effectiveness of the road cleaning process.

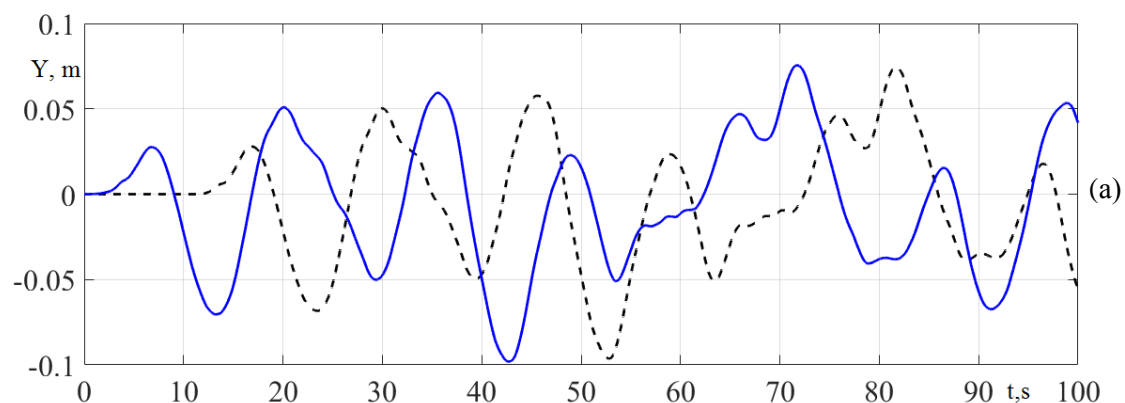
Let us analyse the mathematical model in accordance with the following steps:

1) For the working process of a sweeping machine that is not equipped with a device for controlling the vertical coordinate of the BWE, the time dependence of the change in the pressing force due to a change in the roughness of the microrelief was determined and the vertical coordinates of the cleaned surface and the BWE were compared.

2) For the working process of a sweeping machine equipped with a BWE vertical coordinate control device, the operation is analysed in two modes: with and without an additional pump.

4. Experimental results

Figure 3 presents the results of modelling the working process of a sweeping machine without control device.



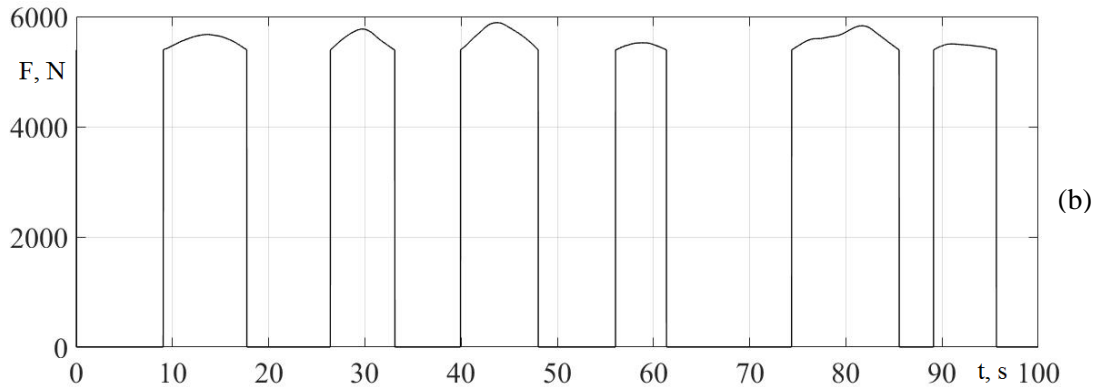


Figure 3. Time dependences of the vertical coordinates (a) and the pressing force of the brush working equipment to the surface being cleaned: the vertical coordinate of the brush working equipment (—), the vertical coordinate of the surface being cleaned (---).

It can be seen from the plots that, at the initial moment of working time (0-10 s), the surface under BWE is flat, but the vertical coordinate of BWE changes under the influence of the surface relief under the front wheels of the machine, as a result of which, during the rest of the working process, there is a mismatch values of vertical BWE coordinates and the surface. At those time intervals where the movement of BWE over the roughness of the roadway is observed, the value of the pressing force decreases. On others, where the vertical coordinate of the surface is greater than the BWE coordinate, there is a sharp increase in the pressing force.

Figure 4 presents the results of modelling the working process of a sweeping machine with a control device of the vertical coordinate of BWE using one regular hydraulic pump. Let us analyse the plots in more detail, considering the time interval from 20 to 40 seconds.

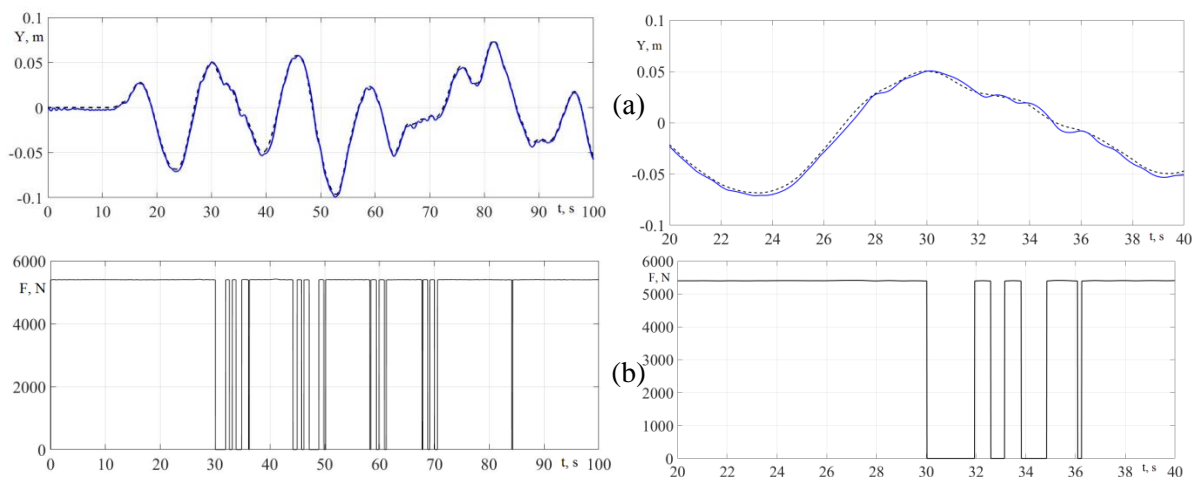


Figure 4. Time dependences of the vertical coordinates (a) and the pressing force of brush working equipment to the surface being cleaned (b) when using a control device with a standard pump and their increased intervals: vertical coordinate of brush working equipment (—), vertical coordinate of the surface being cleaned (---).

The plots show the control device being able to significantly reduce the difference between the vertical BWE coordinates and the roadway. In this case, the pressing force assumes values close to the specified ones; however, in the case of a sharp change in the vertical coordinate of the roadway, the working volume of the regular hydraulic pump is not enough for a timely change in the vertical BWE

coordinate. This leads to the appearance of areas in which the pressing force drops to zero, while the quality of cleaning the road surface deteriorates.

In order to make up for the missing supply of a standard hydraulic pump to the modernised hydraulic system, an additional hydraulic pump was introduced. Figure 5 presents the results of modelling the working process of a sweeping machine equipped with a BWE vertical coordinate control device with an upgraded hydraulic system.

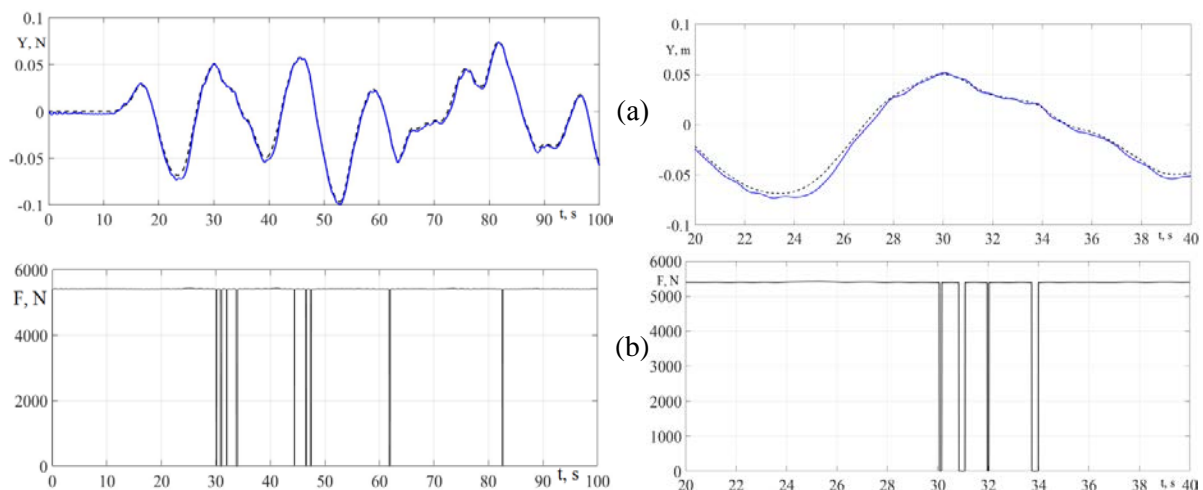


Figure 5. Time dependences of the vertical coordinates (a) and the pressing force of the brush working equipment to the surface being cleaned (b) when using the control device with a modernised hydraulic system and their extended intervals: vertical coordinate of brush working equipment (—), vertical coordinate of the surface being cleaned (---).

It can be seen from the plots that the use of the modernised hydraulic system allowed the control unit with the vertical coordinate of the BWE to almost constantly maintain the required value of the pressing force. The speed of the control device has increased significantly (fewer areas with a decrease in pressing force) confirming the effectiveness of the modernised hydraulic system.

5. Results and discussion

The mismatch of the values of the BWE vertical coordinates and the surface being cleaned appears to be the reason for a decrease in the efficiency of the working process of the sweeping machine, since a decrease in the pressing force leads to a decrease in the cleaning efficiency of the roadway, and an increase in the pressing force leads to increased wear of the BWE bristle and, as a result, to an increase in operating costs. In this regard, the introduction of a BWE vertical coordinate control device seems to be an urgent research task.

6. Conclusions

The developed mathematical model of the sweeping machine working process, as a complex dynamic system, made it possible to optimize the parameters of the device for controlling the force of pressing brush working equipment to the surface to be cleaned and thereby improve the quality of road surface cleaning.

Improving the performance of the brush working equipment vertical coordinate control device is provided by the upgraded hydraulic system of the sweeping machine.

7. References

- [1] Xue C and Hu Y 2014 *Advanced Materials Research* **272** 257–60

- [2] Zhengdong Z, Biwen L, Huihuang L and Feng Z 2018 *Modelling and Simulation* **7** 183–190
- [3] Teterina I A and Letopolsky A B 2016 *The model of the interaction of the alkali metal oxide with the treated surface: monograph*. (Smolensk: LLC NOVALENKO) 73–5
- [4] Yuan X, Yan D, Yonghou X, Kai Ch, Tao X and Shixiang Zh 2017 *Internal IOP Conf. Series: Materials Science and Engineering* **272** 012007 DOI: 10.1088/1757-899X/272/1/012007
- [5] Shcherbakov V S, Belyaev N V and Skuba P Yu 2012 *Automation design of planning machines based on wheeled tractors: monograph*. (Omsk SibADI) p 130
- [6] Ignatov S D and Sherstnev N S 2017 *The Russian Automobile and Highway Industry J.* **3** 120–4
- [7] Shcherbakov V S and Sukharev R Yu 2011 *Improving the control system of the working body of the chain trench excavator: monograph*. (Omsk: SibADI) p 149
- [8] Fasiuddin S N Q 2016 *Proc. of the Int. Conf. on Industrial Engineering and Operations Management 8-10 March* 14–98
- [9] Korchagin P A 2013 *The Russian Automobile and Highway Industry J.* **4** 91–5 [In Russ.]
- [10] Korchagin P A and Teterina I A 2015 *The Russian Automobile and Highway Industry J.* **5** 118–23
- [11] Yang Q L, Zhou Y, Ying K M, Li R B and Wang X 2018 *Proc. of the 2018 3rd Int. Conf. on Electrical, Automation and Mechanical Engineering* **127** 194–8
- [12] Jeon J, Jung B, Koo J C, Pintado A and Oh P 2017 *IEEE Int. Conf. on Consumer Electronics* 72–3
- [13] Wang C, Sun Q, Wahab M A, Zhang X and Xu L 2015 *Waste Management* **43** 19–27 DOI: 10.1016/j.wasman.2015.06.027