The concept of functioning of the on-board quality control system for anti-icing pavement treatment

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Abstract. The article discusses the concept of an electronic system for ensuring the quality of anti-icing processing of sidewalks and other elements of road construction. The object of research is the quality of particle distribution of anti-icing material. In particular, such quality indicators as the width of the processing band, the density of distribution of the material over the coating and the degree of lateral deformation of the processing zone are considered. The subject of the research is the general principle of the control system for the numerical values of the distribution quality indicators. Such a system is based on mathematical models of the movement of individual particles of a material along a flat rotating disk and in air. The original mathematical basis was developed by the authors of the article, taking into account the analytical equations of motion of a particle on a rotating horizontal disk obtained earlier by other researchers and using Newton's second law. The article describes the algorithm for the functioning of the distribution quality control system, which takes into account geometric, regime and meteorological parameters. The system is designed to work with a symmetrical way of feeding material from the tray to the disc. In addition, the physicochemical properties of the particles of anti-icing material and numerical quality criteria are taken into account, such as the required width of the processing strip, the rate of density of distribution (consumption) of the material and the maximum permissible degree of lateral deformation of the processing zone. The block diagram of the system is presented. As a result of the operation of the proposed system, it becomes possible to change the values of the operating parameters of the equipment in the process of material distribution, providing the required values of quality indicators. Thus, the negative impact on the ecological environment of the city will be reduced and the economic efficiency of anti-icing processing of sidewalks will be increased.

1. Introduction

The existing methods of quality control of anti-icing treatment of pavements can be conditionally divided into three groups: control of quality indicators at the stage of certification tests of the machine for the distribution of anti-icing materials; in the process of distributing anti-icing material by the machine; based on the results of a technical and economic analysis of the effectiveness of anti-icing measures. At the stage of certification tests, the width of the distribution of anti-icing material, the step of adjusting the width of the distribution of the material, the uniformity, density and asymmetry of the distribution of the material are controlled.
With the direct implementation of operations on anti-icing processing, the following is monitored: the modernity of the beginning of the distribution of anti-icing material, compliance with the prescribed deadlines for the elimination of winter slipperiness; uniform distribution of material within the carriageway; actual distribution density of the material. The most common way to control the quality indicators of anti-icing processing is onboard electronic control systems. Such systems are able to control the width, direction of distribution and the actual flow rate (distribution density) of the deicing material. In doing so, they take into account the air temperature, the speed of the machine and the operating mode of the distribution equipment. Evaluation and control of the uniformity of material distribution is not performed by modern on-board systems.

The technique of technical and economic analysis of the efficiency of machines for the distribution of materials evaluates the quality indirectly. It uses two indicators: actual economic efficiency based on specific statistics and surveys, and potential (theoretical) economic efficiency.

2. Problem Statement
It is fair to say that the described quality control methods are used for road and airfield surfaces. The quality of the distribution of anti-icing material on the surfaces of sidewalks, footpaths and other elements of road construction is assessed visually. Often the material is distributed manually without observing the norms and special control of the degree of uniformity. Such processing causes increased difficulties for the movement of pedestrians and poses an environmental hazard to humans, animals, plants, soil and microorganisms. Uneven, lumpy distribution of the material indicates a low efficiency of its use and leads to an increase in the cost of anti-icing treatment. This indicates the relevance of developing a new approach to the issue of ensuring the quality of the distribution of anti-icing material on sidewalks.

In this article, a distribution scheme is proposed for use, in which material is fed from a hopper to a disk through a tray with an annular cross-sectional shape (symmetric method). With this method of feeding, particles of material leave the disk simultaneously from each sector bounded by the blades of the disk, at the same speeds. In the conventional method, the material is fed asymmetrically relative to the center of the disc and this creates the preconditions for the subsequent uneven distribution of particles on the disc and in the air. The symmetrical method can be rationally implemented using a disk located at some distance from the machine. Then all the advantages of this method will be maximized. For the proposed equipment and feeding method, it is required to develop an on-board quality control system for the distribution of anti-icing material particles. Such a system should ensure control of the width of the processing strip, the uniformity of material distribution and compliance with the rate of material consumption, taking into account not only the operating and geometric parameters of the equipment, but also meteorological parameters. These include wind speed and direction.

3. Materials and methods
The functioning of the quality control system for anti-icing treatment of sidewalks should be based on mathematical models of the movement of material particles along a flat rotating disk and in the air. The works [1-3] are devoted to the description of the motion of solid particles on a disk using inhomogeneous differential equations of the second order. Modeling the motion of particles in air using Newton's equations is presented in detail in [4, 5]. The results of these studies make it possible to calculate, for given initial conditions, the flight range of particles in the air (width of the processing strip) and to determine, in the presence of wind, the degree of deviation of the processing strip width from the required initial one (which is set in the absence of wind).

The distribution can be considered qualitative if the required processing bandwidth is observed, the consumption rate (distribution density) of the material per 1 m² of pavement and the degree of lateral deformation of the processing area does not exceed the specified maximum value.

The actual density \( q_f \) of the material distribution should be equal to the normalized \( q_n \). Considering the symmetrical way of feeding the material onto the disc, the actual density (flow rate) is defined as:
\[ q_f = \left( \frac{\rho \left( \pi h_i (r_2^2 - r_1^2) \right)}{S_f} \right) \]

where \( \rho \) – the density of anti-icing material, kg/m\(^3\);
\( S_f \) – the actual area of the processing strip, m\(^2\);
\( r_1 \) – the inner radius of the annular tray, m;
\( r_2 \) – the outer radius of the annular tray, m;
\( h_i \) – the disc blade height, m.

The width of the processing lane is set taking into account the maximum width of the sidewalk. The degree of lateral deformation is an important quality indicator, since it allows you to assess how much the width of the processing strip has changed when exposed to wind and quickly make a decision to minimize this impact. It is obvious that an increase in the degree of lateral deformation leads to an increase in the number of machine passes, and, consequently, to an increase in the processing time of the pavement.

The purpose of the on-board control system is to provide a numerical assessment of quality indicators in the process of anti-icing processing and to offer the operator solutions to eliminate the negative impact of the external environment on the processing area. These solutions include options for varying the operating parameters of the distribution equipment, namely, the rotational speed of the disk, the height of the disk above the pavement, and the speed of the machine. In this case, the system takes into account the values of the geometric parameters of the equipment, such as the outer and inner radii of the circular section of the chute, the volume of the hopper with material, the diameter of the disc, the length and height of the disc blades, the angle of inclination of the disc to the axis of rotation, the angle of inclination of the blades to the radial position. The physicochemical properties and particle size distribution of the anti-icing material are also taken into account: density, mass, volume and radius of a particle.

The on-board control system (Figure 1) should contain a control unit with a microcontroller and an associated sensor unit that monitor the speed of the machine and the value of the material consumption, as well as a control panel with a display. The values of the operating parameters are entered into the control unit database. In addition, the calculated dependences of the width of the processing strip and the actual consumption of material on the operating parameters, such as the speed of the machine, the height of the disc above the coating and the rotational speed of the spreading disc, are introduced. Additionally, the sensor unit must be equipped with a sensor for measuring the speed of the machine (speed sensor), a manometer (pressure gauge), a sensor for measuring the flow (supply) of material to the disk (flow meter), sensors for measuring the speed and direction of the wind (anemometer), and also for measuring linear (linear displacement transducer – LDT, Figure 1) and angular displacements of the disc, namely, the height of the disc above the pavement, the angle of inclination of the disc to the axis of rotation (angular displacement transducer – ADT1, Figure 1) and the rotational speed of the disc (ADT2, Figure 1).
In addition, when forming the information base in the control unit, the values of the geometric parameters of the distribution equipment are taken into account: the diameter of the distribution disc, the length, height and number of disc blades, the outer and inner radii of the circular section of the chute, and the volume of the hopper with material. The control unit is entered with the current values of meteorological parameters, that is, the actual values of the direction and speed of the wind, as well as a database on the physical and chemical properties and particle size distribution of the anti-icing material. In the memory of the microcontroller, information is entered with a description of the mathematical models of the movement of material particles through the distribution equipment and in the air, as well as the calculated dependences of the width of the processing strip, the degree of lateral deformation of the processing zone and the actual consumption (distribution density) of the material on geometric, operating and meteorological parameters. Numerical criteria of the distribution quality are also introduced - the normalized distribution density of the material under ideal conditions and the permissible deviation of the width of the processing strip under real distribution conditions from the width in the absence of wind. Directly in the process of material distribution, the width of the processing strip, the actual distribution density of the material per 1 m² of pavement is calculated and the degree of lateral deformation of the processing zone is numerically determined. If the required values of the above quality indicators are not achieved, as well as if the degree of lateral deformation of the processing zone exceeds the permissible maximum value, then the system selects the operating parameters of the equipment using databases with mathematical models and numerical criteria for the distribution quality.

**Figure 1.** Structural scheme of the system
The display shows possible options for varying certain operating parameters to improve quality indicators. The specific choice is made by the operator using the initial data input unit.

4. Discussion

It is necessary to clearly explain the essence of the concept of functioning of the quality control system for pavement processing. To do this, consider how, with the initial parameters set, individual quality indicators can be controlled.

Let the initial geometric parameters be the following data (Table 1).

| Parameter                        | Value       |
|----------------------------------|-------------|
| Length of disc blade             | 175 cm      |
| Height of disc blade             | 5 cm        |
| Angle of disc blade              | 45°         |
| Outer radius of tray             | 10 cm       |
| Inner radius of tray             | 4 cm        |
| Diameter of disk                 | 180 cm      |
| Angle of inclination of the disk | 90°         |
| to the axis of rotation          |             |

A solid anti-icing material with a density of 1150 kg/m$^3$, with an average particle diameter of 0.25 cm and a required distribution density of 90 g/m$^2$ was selected for distribution. The required width of the processing strip is 0.52 m, the maximum allowable degree of lateral deformation of the zone is set equal to 10% of 0.52 m.

Meteorological conditions are described by the following parameters: wind speed 8 m/s, north-east wind, steady direction, moderate, the speed vector is directed at an angle of 10 degrees. to an axis perpendicular to the direction of travel of the machine. The air temperature is -5 °C, the air density is 1.3163 kg/m$^3$, the dynamic viscosity of the air is 0.000017 Pa s.

The initial operating parameters of the equipment are described in Table 2.

| Parameter                        | Value       |
|----------------------------------|-------------|
| Disc height above cover          | 400 cm      |
| Disk rotation speed              | 390 rpm     |
| Machine speed                    | 20 km/h     |

After entering the initial data, the width of the processing strip is calculated, which in the absence of wind is 0.52 m.

Taking into account the effect of wind on the processing area, the calculated actual value of the processing strip width is 0.4609 m. The degree of lateral deformation of the processing area is 11.37%.

It can be concluded that the required width of the processing strip has not been reached and when the maximum permissible degree of lateral deformation of the processing zone is set at 10%, the quality of anti-icing processing has not been achieved.

Reducing the negative consequences of deformation of the processing zone can be achieved if the height of the disc above the coating is changed to 0.5 m. Then, the width of the processing strip will be 0.52 m.
Another option can be proposed, namely, increasing the value of the disk rotation speed to 7 s\(^{-1}\). Then the strip width will be 0.53 m, therefore, a complete elimination of the degree of deformation of the treatment zone is achieved.

The system, based on the calculated data, provides the operator with the opportunity to choose one or another strategy for controlling the parameters of distribution equipment. A control panel with a display is used to display and enter information.

It should be noted that such systems for equipment distributing material along sidewalks using a symmetric feeding method have not been described previously, therefore, the development of the concept needs further development and research.

5. Conclusion
The concept of the on-board anti-icing quality control system proposed in the article is a new approach to solving the problem of eliminating the uneven distribution of anti-icing material on sidewalks and other elements of road construction. It is based on the implementation of a symmetrical method of feeding material from a tray to the surface of the disc and involves placing the disc on a remote rod. The quality control system assumes taking into account the meteorological parameters of the external environment, which have a significant impact on the shape of the processing zone, since it is not characterized by large dimensions. Such a system does not include expensive equipment and can be used for winter maintenance of sidewalks, bridges, footpaths, providing an economical use of materials and reducing the negative environmental impact on the environment and the human body.

References
[1] Hofstee J W and Huisman W 1990 Handling and spreading of fertilizers: part 1, physical properties of fertilizer in relation to particle motion Journal of Agricultural Engineering Research 47(4) 213–234
[2] Liedekerke P Van, Tijskens E, Dintwa E, Anthonis J and Ramon H 2006 A discrete element model for simulation of a spinning disc fertilizer spreader I. Single particle simulations Powder Technology 170 issue 2 71–85
[3] Villette S, Cointault F, Piron E and Chopinet B 2005 Centrifugal Spreading: an Analytical Model for the Motion of Fertiliser Particles on a Spinning Disc Biosystems Engineering 92 issue 2 157–164
[4] Mandrovskiy K P and Sadovnikova Y S 2018 Characteristics of the droplet motion of a liquid antifreeze reagent Magazine of Civil Engineerin 03 14–26
[5] Mandrovskiy K P and Sadovnikova Y S 2019 Modeling the Uniform Treatment of Coatings with an Anti-Icing Liquid Reagent Mathematical Models and Computer Simulations 11(5) 842–849