The research of resistance to snow cutting and moving with an auger of a small-sized rotary-auger snowplow

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Abstract. Small-sized rotary-auger snowplows are being used to remove snow from pavements, areas near houses and in cramped conditions. To design and operate such snowplows, it is necessary to know the resistances that arise in the process of interaction of the working bodies with snow. The article describes the design of the laboratory stand “Ground channel” and the order of the experimental study to determine the resistance to snow cutting and moving with a screw of a small-sized snowplow. The paper presents the values of the total resistance on the screw feeder, depending on the frequency of rotation of the working body and the thickness of the cut snow layer.

1. Introduction
For most regions of the Russian Federation, the issues of winter maintenance of roads and territories remain relevant for almost half of the calendar year. Timely and regular works on snow cleaning and combating winter slippery conditions ensures uninterrupted and safe movement of vehicles and pedestrians. Particular attention should be paid to the areas adjacent to apartment buildings, public buildings and institutions, public transport stops, etc., where traffic is quite busy, especially in the morning and evening hours. Snow removal from local areas is mainly done by wipers manually, who do not complete the entire scope of work in a timely manner every time. Snow is a continuously changing environment, the mechanical properties of which change thousands of times or more [1,2]. The influence of atmospheric effects and the occurrence of snow cover, the intensive movement of pedestrians and vehicles during snowfall or after it, lead to a rapid compaction of snow [3,4]. Cleaning the surface from the compacted and icy snow mass leads to a significant increase in the labor and energy intensity of the process [5], as well as the complication of the snow removal technology.

2. The main part
The winter maintenance of sidewalks, near-house territories and intra-block drives using small-sized snowplows differs from the winter maintenance of highways by a number of technological and organizational features. Small-sized rotary-auger snowplow machines are being used to clean freshly fallen snow with a density of 100 ÷ 400 kg/m3. The working body of such snowplow consists of an
auger feeder and a blade rotor mounted on a uniaxial self-propelled chassis (Figure 1). The auger allows to create a more compact and maneuverable design of a rotary-auger snowplow compared to a milling rotary snowplow, which is equipped with a multiple run milling cutter. Such mill has a large cutting surface, which leads to an increase in the energy consumption of the snow-cutting process for the feeder [6], and this is undesirable for small-sized snowplows having engines with a capacity of up to 10 kW. With the help of two independent power take-off shafts, torque is transmitted from the engine to the working body and the driving wheels. During the stepwise movement of the snowplow, the auger feeder, having the right and left direction of the turns, cuts and moves the snow from the edges to the central part, where the vane rotor is mounted in a common space behind the feeder. High-speed rotation of the rotor impeller causes snow to fall in a given direction by means of an exhaust nozzle. Such designs of small-sized snowplows are quite productive and are capable of throwing snow in the shortest possible time, and also have small dimensions and weight, which simplifies the control and maneuvering in cramped conditions.

![Figure 1. Small-sized rotary-auger snowplow.](image)

Many methods for calculating the basic parameters of snowplows are based on the most significant resistances that occur during the operation of the machine [7], and have a number of specific assumptions, due to the complexity of the processes occurring during the interaction of working bodies with snow [8,9]. Resistances that occur on the working bodies of small-sized low-speed snowplows with a small width are not researched enough yet, and differ sharply from high-speed snowplows based on trucks and tractors in many specific indicators [10].

Solution of the problem of calculation and design, determination of the optimal parameters and forecasting the development of the working bodies of construction, material handling, road, utility machines and equipment remains one of the topical directions of scientific research. The choice of design parameters and the assignment of operating modes of the working bodies of machines under specific operating conditions cannot be made without a comprehensive study of the process of interaction between the working body and the developed medium [11]. Scientific studies of the working bodies of machinery and equipment are carried out mainly in three areas:

1. mathematical modeling using software;
2. physical modeling on special laboratory stands;
3. reproduction of working processes in natural conditions on the structures of the working bodies of existing machines.

Due to the lack of data on resistance to snow cutting and movement with an auger of a small-sized snowplow [12,13], we measured horizontal, vertical and lateral components of the force of resistance to snow cutting and movement by an auger feeder mounted on a soil trolley at the laboratory stand “Ground channel” (figure 2) [14]. Single-pass auger with a diameter of 0.2 m is made in the form of an axial belt blade of metal sheet, welded to a shaft with a diameter of 0.06 m, with a width of 0.6 m and a screw pitch of 0.2 m, while the angle of elevation of the helix of the outer cutting edge auger is 17.7 °. The
working body is driven into rotation by an electric motor using a toothed-belt transmission located on the left. A welded metal subframe, which is bolted to the intermediate frame of the laboratory stand, is provided for the installation of the drive, attachments and protective case. On both sides of the subframe, there are quick-release bearing supports for fastening the shaft of the studied working body.

![Laboratory stand "Ground channel" with an auger.](image)

**Figure 2.** Laboratory stand "Ground channel" with an auger.

The intermediate frame with the installed working equipment is attached to the hinged frame of the undercarriage of the laboratory stand with the help of seven strain gages: four horizontal, two vertical and one longitudinal. The readings from strain gauges were taken using an analog-to-digital converter LTR-212 (L-Card) connected to a laptop and recorded with the PowerGraph software. We used Delta frequency converter to carry out an experimental study at various speeds of rotation of the auger, and the ATV 2500LB automobile traction winch to move the trolley at a speed of 0.23 km/h along the rails of the laboratory bench.

The experimental study took place in March 2019 in natural conditions on wet snow with an average density of 400 kg/m³ at an ambient temperature of -5 ... 0 °C. The task of the study was to determine the resistance to snow cutting and movement by the auger, depending on the frequency of rotation of the working body and the thickness of the cut snow layer. Before each experiment, the channel of the laboratory stand was filled with snow, and its surface was leveled with a grading rail. The parallelogram attachment of the hinged frame to the undercarriage of the laboratory stand allowed the working body to be buried to the required depth using screw mechanisms. The thickness of the cut snow layer was set using a metal ruler and was 25, 50, 75 and 100 mm. After checking the receiving signals from each strain gauge link, we began their calibration, followed by a switch to the data recording mode. The required frequency of the electric current was set on the frequency converter, and the drive of the working device was turned on with a rotation frequency in the range of 300-700 rpm. Then the traction winch was connected to drive the undercarriage of the laboratory bench. In the course of the experiment, horizontal, vertical and longitudinal components of resistance to snow cutting and movement by an auger were recorded in the form of oscillograms (Figure 3) taking into account the calibration coefficients of each tensometric link.
After the auger feeder cleaned the targeted section, the drive of the undercarriage and the auger was turned off, and the recorded data was saved on the laptop. The undercarriage returned to its original position at the beginning of the channel, and the cycle was repeated anew, starting with the loading of snow into the channel of the laboratory stand, its compaction and leveling. The experiments were repeated as many times as necessary, according to the plan of the experiment.

The results of the experimental study were processed by the average peak values of the resistance to snow cutting and movement by the auger during the steady movement of the undercarriage, which corresponded approximately to the middle part of the movement path. Based on the horizontal, vertical and longitudinal components of the resistance forces, we determined the total resistance that occurs when the auger is in operation at the current time. After processing all the oscillograms obtained in the course of laboratory experiments, we received the graphs of the values of the total resistance on the auger feeder of a small-sized snowplow, depending on the rotation frequency of the working body and the thickness of the cut snow layer (Figure 4).

**Figure 3.** The characteristic form of the original oscillogram.

**Figure 4.** Total resistance to snow cutting and moving by an auger.
3. Conclusion
Based on the obtained results, we can conclude that the depth of the working body leads to an increase in the total contact length of the cutting edge of the auger with the developed medium. Therefore, with an increase in the thickness of the cut snow layer, the total resistance on the auger feeder grows mainly due to the horizontal and vertical components responsible for cutting snow from the array. Moreover, the amount of snow mass, simultaneously moving along the shaft of the auger, increases as well, which leads to a slight increase in the longitudinal component of the resistance force. It should be noted that in real constructions of small-sized snowplows the longitudinal component is almost zero during snow removal due to the right and left execution of the auger turns, which balance each other. We noted that for large thicknesses of the cut snow layer (75 and 100 mm), additional resistance occurs on the shaft of the auger feeder, which partially compresses the snow during the stepwise movement of the snowplow.

In the course of the experimental study, we found that at the speed of movement of the undercarriage of 0.23 km/h, the rotational speed of the working body in the range of 300–400 rpm is hardly enough to completely remove a 100 mm thick layer of snow. This is due to insufficient performance of the auger feeder. To ensure effective cleaning of the surface from a high layer of snow with small total resistances and a low auger rotation speed, it is necessary to reduce the translational speed of the snowplow. We should take into account that reducing the working speed of movement leads to a decrease in the performance of the machine as a whole [15]. On the other hand, work at high rotational speeds requires a lot of power to drive an auger feeder, especially when the snow layer is of small thickness, when the total resistance on the working member increases 2-4.9 times for the snow layer 100 and 25 mm respectively. The ratio of the optimal speed of movement of the base chassis and the frequency of rotation of the auger at different thicknesses of the snow layer is a task for further research in this direction.

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