Studying the Machines for Road Maintenance

Mikhail Vasilievich Doudkin, Sergey Nikolaevich Fadeyev and Sergey Yurievich Pichugin

D. Serikbayev East Kazakhstan State Technical University, Ust-Kamenogorsk, Protozanova st., 69, 070004, Kazakhstan
london_690@mail.ru

Abstract: Removing ice and snow from highways and walkways in the Northern Hemisphere is a major budget item for States, Provinces and municipalities during winter months. Many countries in the world experience winter weather of sufficient severity to create hazardous situations. Freezing rains and compacted snow often accumulate on roads and sidewalks creating dangerous and sometimes even fatal conditions for automobile and pedestrian traffic. Just look at the record of emergency units for statistics of broken legs and arms during winter period. Now the machines with the working element like a blade and hand impact tools are used for chipping snow-ice formations from the road and sidewalk surfaces. And the machines can easily damage the road surface with the blade, besides, they are large-dimensioned. Hand impact tools demand the direct human physical force and low are not effective because of poor efficiency. The design of this machine will allow to prevent dangerous situations on the roads during icing and not damage the road surface.

[Doudkin M.V., Fadeyev S.N., Pichugin S.Y. **Studying the Machines for Road Maintenance.** *Life Sci J* 2013;10(12s):134-138] (ISSN:1097-8135). http://www.lifesciencesite.com. 24

Keywords: ice, road, chipping, hammers, working element.

1. Introduction

With new practices emerging the world industry, especially “just-in-time” manufacturing principles, economic aspects of having roads and sidewalks free of ice should also be considered in addition to safety concerns. For best results, those innovative supply chain procedures require not so much a low average transit time between locations, as low value of standard deviation on that average transit time [1]. Such a low standard deviation is best obtained by ensuring good winter maintenance practices.

Density of snow-ice deposits greatly depends on environmental and climatic conditions. Generally, it increases with the increase of the humidity. Besides that, compactness of snow-ice deposits is affected by air temperature [2]. As shown in Table 1, the higher the temperature, the more compacted the snow is. Density of ice also increases with the increase of wind velocity. Compacted snow temporary melts under motor transport wheels even if the air temperature is below zero, even though, tire specific pressure is relatively low - for high-pressure tire it is 8-10 kg/sm^2, for low-pressure tire it is 2-5 kg/sm^2.

In cities temperature of snow and ice on roads can be significantly higher than air temperature because they are well heated by soil and various underground structures, and also from solar radiation on sunny days. This is especially important for asphalt layer, which is a good absorber of a solar energy.

If snow-ice crust lays on the road surface for a long time, it becomes more uniform and smooth after repeated melting and freezing. Snow-ice crust chipped from the roads during a thaw, after being compacted by vehicles for a long time, reaches average density of 0.73 t/m^3. On the other hand, the density of ice formed on roads reaches approximate density of 0.9 t/m^3 [3], depending upon the snow parameters given in Table 1. The other properties of snow-ice deposits are listed in Table 2:

Table 1. Parameters of snow

Parameters of snow	Percentage, %	Rupture strength, MPa	Brittle strength, MPa
Muddiness	4.85	2.4	1.65
Porosity	4.3		

Fighting winter road conditions is a never-ending task. When travelling throughout Central Asia in winter time, one may often see road workers chipping ice with chisels and then loading those broken chunks onto trucks. In North America, means for ensuring good road conditions (typically termed "bare pavement" conditions) traditionally comprise salting, sanding and scraping. Every method of road cleaning has some drawbacks; salting is damaging road surface and corroding automobiles, scraping also damages road surface [3, 4]. On the other hand, sanding is only a half measure that can temporarily improve road conditions while not addressing the main problem, which is ice removal. Lately, there are increasing concerns about the environmental impact of salting and sanding, and also their harmful effect on transportation infrastructure. Accordingly, there is a great interest in improving mechanical means of road cleaning, while avoiding disadvantages of scraping. Such new methods should offer a possibility to clean sidewalks and other areas that are not accessible for heavy equipment.

Table 2. Properties of snow-ice deposits upon compactness

Description of snow-ice deposits	Average of snow-ice deposits density in t/m^3	Range of Description of snow-ice deposits in t/m^3	Notes
New - fallen, not compacted	0.12	0.115-0.125	Period of being on the road: up to 24 hours
The same, after compacting	0.2	0.18-0.22	t = -2° c
Not fresh, dirty, after compacting	0.26	0.23-0.29	Period of being on the road: from 1 to 15 days
Not fresh, dirty, collected from the streets with a little traffic, after compacting	0.34	0.32-0.36	-
Old, very dirty, collected from the streets with busy traffic, after compacting	0,46	0,45-0,48	Period of being on the road: from more than 15 days
Chipping from streets	0.73	0.69-0.77	-
New-fallen after cleaning with snow-removal machinery	0.25	0.210-0.284	t = - 2° C

An interesting and unique concept of mechanical ice removal has been recently developed at East Kazakhstan State Technical University (EKSTU) in Ust-Kamenogorsk (Kazakhstan). The method was specially designed for Central Asia, but it can be easily adapted for road conditions in the US, Canada and Northern Europe. This concept utilizes the technique of ice breaking and chipping rather than scraping. The process includes pulverizing and breaking the ice into smaller fragments that can be easily removed. Chipping is preferable to pulverization because it is much less energy intensive. Ice breaking and chipping is accomplished by a number of "hammers" installed on a rotating drum. Hammers hit the ice surface with a sufficient force to break it to smaller pieces, which can be then removed by plow or other means.

The model of a working element is shown in Figure 1 while the front view of the same element installed on a working model is photographed in Figure 2.Steel disks, distanced approx. 25-30mm apart are installed on a common rotating shaft. Special geometry steel hammers are then axled between each disk. The fabricated prototype has four (4) hammers, installed 90 degree apart in each space between disks. Hammers are installed loosely and are free to rotate around their axis. When the entire drum with disks rotates, hammers are unfolding due to centrifugal force (see Figure 2) and hit the ice surface with a force, which can be further adjusted by rpm of the drum. The force magnitude has to be adequate to break the ice but not high enough to damage the asphalt or concrete surface underneath. It has been found experimentally that ice breaks at the stress of approx. 0.2 MPa and asphalt can withstand 3-5 MPa.

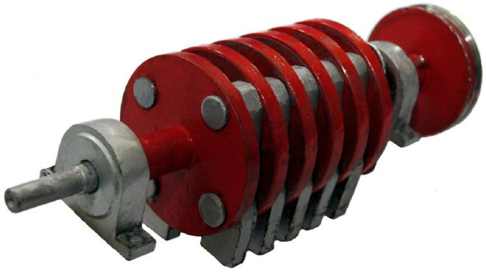

Fig. 1: Working element of an ice-breaking machine. Visible steel hammers (grey) loosely axled between disks (red), which in turn are mounted on a common shaft.

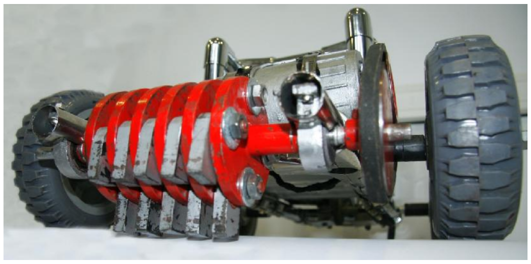

Fig. 2: Frontal view of a model showing hammers unfolding under gravity force. Similarly, they are unfolding during drum rotation due to centrifugal force.

During lab and field experiments, the concept had well proven itself to handle both ice and packed snow within a broad range of climatic conditions. While this technology can be scaled-up and adapted for mounting in the front of heavy ice-removal trucks, the first prototype was designed and fabricated for ice breaking on sidewalks and walkways as this was a major problem in many Central Asian towns. The hand-held, self-propelled machine, designed to be operated by one person can be powered by either electric or gas engine. Our search of literature and catalogues showed that this is most probably the first such portable machine for ice breaking in the world since other similar equipment was designed only to handle snow, eventually impacted snow [5].

The design is shown in Fig.3. The drum has a length of 0.5m, therefore, a strip of ice with such a width could be removed at one run at the speed of 1000 m/hr. The power requirement for the prototype of this size was 3kW and the machine was capable of breaking ice layer with a maximum thickness of 65mm. The thickness can be further controlled by the size and geometry of hammers. As observed during the study, the ice has the tendency to chip in larger chunks thus becoming easier to break once its thickness exceed certain value, which is usually around 15-20mm. This was well documented in earlier studies, among others from Iowa Dept of Transportation [6]

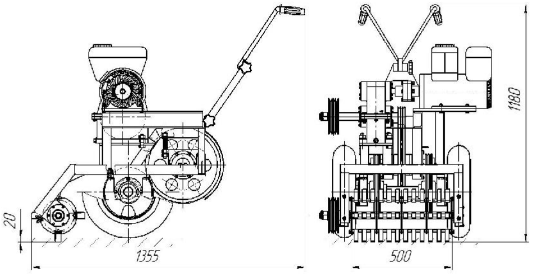

Fig. 3: Design of a hand-held self-propelled ice breaker for sidewalks

With drum rotation at 2100 rpm and the mass of each hammer being 0.3kg, the impact force achieved per each hammer was 28N, and considering its impact area, the combined compression and impact stress at the ice surface was 0.2MPa, which was sufficient for breaking and chipping.

Extensive investigations both in the laboratory and field were carried out in order to establish the best size and geometry of a hammer [7]. Figure 4 shows three types, which were used in these experiments. The first one (a) was a standard rectangular shape, and it was the best for an ice at temperatures below freezing. On the other hand, at higher temperatures, when ice becomes wet, the best hammer geometry was (b), designed with two edges in order to hit the ice surface twice during each impact. The first impact usually breaks the ice, while the second one drags the broken chunk toward the back. For packed snow, the optimum hammer geometry was found to be (c) with rounded end.

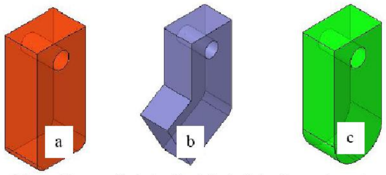

Fig. 4: Types of hammers for ice breaking:(a)for ice below freezing temperatures, (b) for wet ice, (c) for packed snow.

Major objectives of experimental studying packed ice breakup on roads were the following: experimental model functional test; determining capacity and the possible snow thickness broken with the equipment single pass; and also determining working element parameters and its working modes when the maximum efficient snow and ice removing from the road surface is achieved without any damage of the asphalt or concrete surface underneath [7, 8].

Field investigations were done directly on the road surface with 10…50 mm thickness of packed snow. The snow compactness was measured with the specific tool which was also used to sample, measure its volume; after snow melting the tool was used to determine the liquid volume and mass.

The measurements were done in several points and the average density was determined ranging from 0.57 to 0.59 g/sm^3. Air temperature ranged from - 17 °C to -19 °C. The experiments have established that the machine forward motion rate decreasing to 2.5 km/h improves the surface cleaning quality; and the thickness of broken snow in a single pass reaches 30…40 mm at working element revolutions speed of 2000...2500 rpm. The machine speed increasing up to 5...5.4 km/h keeps the quality down and on snow thickness of 10…15mm; areas with unbroken compacted snow could be observed.

Fig. 5: The experimental machine working element

The efficiency of the working process of compacted snow breaking for full-scale machine is 3000...4000 m^2/h in one pass for compacted snow thickness up to 30...40 mm. An important reserve of cleaning quality improving and efficiency of compacted snow breaking on road surfaces is increasing hammers rotation frequency up to 3000 rpm and machine speed 2.5...3 km/h.

Hammers – additional breaking up elements – make a salient feature of this working element design. The machine working elements present the roll with mounted breaking up tool with hammers fixed by joints [9]. When the machine working element rotates hammers chip the ice.

The working element position is controlled so that the hammers did not touch the road surface and did not damage it. Such design allows to match the surface and limit critical load on the working element when it meets an obstacle on the road.

Fig. 6: Snow-ice chipping process

Fig. 7: Cleaned road surface

We also established the effect of the machine forward speed on compacted snow breaking up capacity. Speeding up to 5.4 km/h sufficiently increase the stress on working equipment, particularly on thick compacted snow. This effect was established.

The result of testing the experimental ice-chipping machine with the roll and fixed hammers for breaking up compacted snow, have proved the abstract theorem being the basis of new equipment type design, actual working processes of breaking up compacted snow by strain energy method.

The most important parameter describing the process of ice removing from road surfaces is energy consumption during that process. Both running torque and feed thrust change with their magnitude and period of oscillation from minimum to maximum values during a full turn of a working drum [10]. Therefore, chipping capacity is calculated by taking maximum forces that affect working element and are practically irrespective of the angle of working element, we get the equation for determining given parameter:

$$N_c = v_n P_m + \omega M_r \quad (1)$$

where: N_c is chipping capacity, kW;

v_n is feed rate, m/s;

ω is angular velocity, m/s^2;

M_r is running torque, N*m;

P_m is feed force, N;

Thus, capacity for breaking removed snow and ice may be determined as a product of running torque on rotational velocity of impact working element. As maximal values of feed P_m and running torque M_r occur for P_m at impact moment, and for M_r it occurs during cutting the removed environment from cleaned surface, equation (1) can be presented as:

$$N_c = v_n[n_n P_i cos\varphi] + \omega[n_n(P_{cut} + P_f)(S' - y_k + L_s)] \quad (2)$$

where: P_i is impact force, N;

n_n is number of hammers in one plane perpendicular to axis of rotation, units;

φ is the angle of hammer interaction with icy surface, grad;

P_{cut} is cutting force, N;

P_f is friction force, N;

S' is the distance from fixturing point to actuator cylinder to striker fixturing point, m;

y_k is striker prior deformation, mm;

L_s is the distance from impact surface to striker gravity center, m.

Approximate calculation of impact capacity shows (Figures 8 and 9), that during removing ice from the territory with special impact working element, 6% of machine capacity is spent on removing, and 94% of its capacity goes on ice chipping, that is, power for moving a machine with working element is also effected with ice chipping parameters.

The work was performed under the project «Technology of Separate Making Concretes Using Natural and Anthropogenic Raw Materials» (grant of Ministry of education and science of the Republic of Kazakhstan, contract No. 84-210-13, 10.04.13). The authors express their gratitute to Professor M.

Bergander for his assistance and consulting for writing the given paper.

In conclusion, an innovative technology for mechanical means of ice breaking and chipping has been developed and its feasibility was proven during laboratory and field testing in Central Asia. Further, the prototype has been fabricated for cleaning sidewalks and other hard-access area. It appears that this concept well responds to needs of replacing augmenting present methods of road cleaning, such as salting, sanding and scraping and can be easily adapted to road conditions in North America.

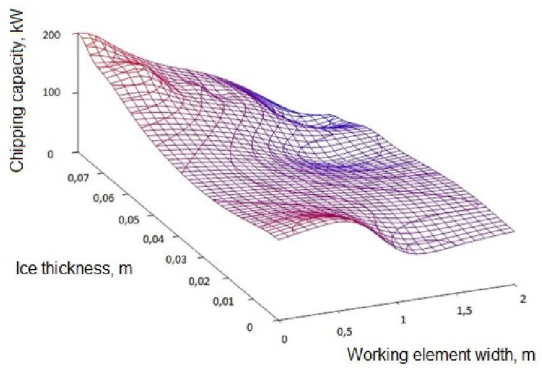

Fig. 8: Dependence of capacity for ice chipping upon its thickness and working element width

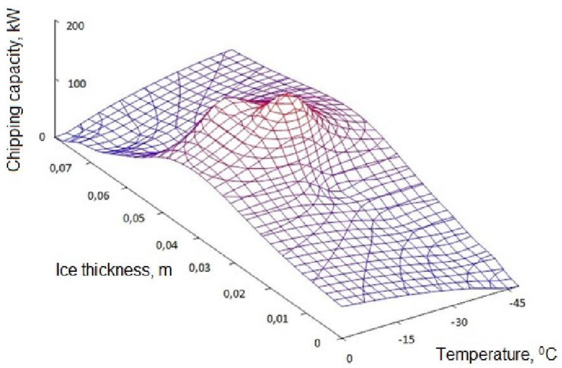

Fig. 9: Dependence of capacity for ice chipping upon its thickness and air temperature

Corresponding Author:
Dr. Doudkin,
D. Serikbayev East Kazakhstan State Technical University, Ust-Kamenogorsk, Protozanova st., 69, 070004, Kazakhstan
london_690@mail.ru

2/11/2013

References

[1] Ninon W.A., Gawronski T.J., and Whelan A.E., Development of a Model for the Ice Scraping Process, Iowa Dept. of Transportation, Project HR361.

[2] Wooseung Jang, James S. Noble, Thomas Hutsel, 2010, An integrated model to solve the winter asset and road maintenance problem Journal: Iie Transactions, vol. 42, no. 9, pp. 675-689.

[3] Doudkin M.V., Pichugin S.Y. and Fadeyev S.N., 2013, The Analysis of Road Machine Working Elements Parameters, World Applied Sciences Journal 23 (2): 151-158, ISSN 1818-4952.

[4] Carola A. Blazquez, Alejandra Beghelli, Veronica P. Meneses, 2011, A novel methodology for determining low cost PM10 street sweeping routes, Journal: Journal of The Air & Waste Management Association - J AIR WASTE MANAGE ASSOC , vol. just-accep, no. just-accep.

[5] Voskresenskiy G.G., 2009, Selecting Parameters of Compacted Snow Vinro-Chipper. Science and Engineering in Road Sector: No.3. - pp. 38-41.

[6] Gurkan Erdogan, Lee Alexander, Rajesh Rajamani, 2011, Closed-loop snowplow applicator control using road condition measurements, Journal: Vehicle System Dynamics - VEH SYST DYN , vol. 49, no. 4, pp. 625-638.

[7] Voskresenskiy G.G., 2009, Fundamentals of Breaking Compacted Snow on Highways / G.G. Voskresenskiy, — Khabarovsk: Edition of Pacific Ocean State University, 2008. - 250 pp.

[8] Nathalie Perrier, André Langevin, Ciro-alberto Amaya, 2008, Vehicle Routing for Urban Snow Plowing Operations, Journal: Transportation Science, vol. 42, no. 1, pp. 44-56.

[9] Doudkin M.V., Guryanov G.A., Rakhimbekova M.U., Gulcheev A.E. “Working Element for Chipping Ice on Highways”, Innovative patent No. 23188 the Republic of Kazakhstan, MPK E01H 5/12 (2009.01),. – No.2009/0969.1.; 15.11.2010 Bul. No.11.

[10] Erik Furusjö, John Sternbeck, Anna Palm Cousins, 2007, PM 10 source characterization at urban and highway roadside locations, Journal: Science of The Total Environment - SCI TOTAL ENVIR , vol. 387, no. 1, pp. 206-219.