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A design on centrifugal ice breaking and snow removal system based on ADAMS

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ABSTRACT
In this thesis, a new centrifugal ice breaking and snow removal system is designed to solve the problems of ice and snow removal machines, such as low efficiency, poor pavement protection ability and high cost. This system is composed of centrifugal ice breaking unit, drive unit, adaptive unit, walking unit and ice shovel and snow removal unit. This system uses the rotation trundle to drive the rotation of the ice breaking hammer jointed by the hinge and the ice layer will be scrapped after the kinetic energy of the ice breaking hammer reaches the critical damage the ice breaking needs so as to attain the goal of ice breaking; it uses the rotate mode to load the round brush or rolling shovel to remove ice and snow. Different functions can be realized through shifting function keys. During the design process, the ADAMS software is used to make the 3D simulation model and the data acquired through simulation are used to optimize the structure design in order to improve the efficiency and quality of system design.

KEYWORDS
Centrifugal; Ice Breaking and Snow Removal; Ice Breaking Hammer; Round Brush; ADAMS

1. Introduction

Snow clearing machinery is specialized maintenance equipment for roads in winter, which can timely clear the snow and ice on the roads and ensure the safety of pedestrians, vehicles and aircraft. In winter, freezing road can easily lead to traffic accidents and cause road traffic disruption, airports closing, rail outage and the like [2]. Especially under the condition of larger temperature variation after snowing, and freezing roads due to slow snow clearing, traffic safety is under great threat, even seriously affecting the industrial and agricultural production and people's daily lives, and causing great loss to the national economy. After years of development, the type and number of vehicles increase and the speed of traffic improves continuously, so that traffic safety issues in winter days become more obvious. While freezing road is the biggest risk of traffic safety, most expressways restrict the driving speed or have to close for several days to avoid accidents, which severely restrict economic development. Faced with traffic disruption, automobiles and aircraft brake failure, how to improve the running state of the road and stop "white killer" in sleet and snow weather is an important issue; the main method to ensure smooth traffic in winter is to rapidly and effectively remove the snow and ice on the road, so as to guarantee traffic and pedestrian safety[15]. Specialized snow clearing equipment are still lacking in China, and as conventional snow clearing method like artificial and chemical methods will produce a series of negative effects, the application of mechanical snow clearing is flexible, and has less environmental pollution, higher efficiency, which is fit for freezing road characteristics in China's snowfall area. For the characteristics of the climate and geographical environment in China, and based on the characteristics of the compacted snow and ice of all types of roads, researching and developing machinery of higher adaptation level that can quickly remove snow and ice has become a subject to be studied urgently in the winter.

On the basis of analysis on the operating environment of centrifugal icebreaking and snow clearing system and insufficient existing de-icing equipment, the following requirements are proposed for centrifugal icebreaking and snow clearing system.

(1) Having good de-icing effect for ice of different thicknesses within a certain range;
(2) Effectively cleaning up crushed ice and snow, to prevent secondary backlog;
(3) Trying to reduce energy consumption while ensuring the de-icing effect;
(4) Being able to use modular design to reduce costs.

To meet above requirements, the mechanical structure design of centrifugal icebreaking and snow clearing

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device mainly includes the following six parts: structural design of load bearing vehicle, design of transmission mechanism, design of centrifugal icebreaking mechanism, design of ice-shoveling and snow-blowing mechanism, design of self-adaptive damping mechanism and design of modular unit.

This paper studies how to efficiently remove the ice and snow on the roads in the ice or snow disaster, designs and develops a new centrifugal icebreaking and snow clearing system suitable for China's national conditions. Project team independently completes the design of the system's mechanical structure, the selection and purchasing of common components, the processing of mechanical components, the installation and debugging of the machine, and the building of improved design and environment. We finally successfully develop a small icebreaking and snow clearing model machine, the working environment temperature of the model machine can reach at -20°C, and for the rugged features of road, the device that is adaptive to rugged road is designed, so it has stronger practicality. Centrifugal icebreaking and snow clearing system can be driven by gasoline engine as well as manual pushing. Since the key part achieves modular design, material utilization is improved. All the design, processing, making, installing and debugging of the model machine are conducted by simulating the actual requirements of the project, and the overall performance and key technical indicators have met the design requirements.

2. Related work

At present, foreign snow and ice clearing forms are mainly chemical clearing method, thermal clearing method, comprehensive clearing method and mechanical clearing method [16]. Thermal and chemical clearing method is primarily to convert snow and ice into the liquid that can be easily treated by heat and chemical drug, but such methods have the problems of large energy consumption, environmental pollution and serious road corrosion. Comprehensive clearing method is binding several snow clearing ways like melting snow, blowing snow and pushing snow, and it is to conduct advance and return movement with a snow clearing shovel containing multiple sets of tools, to periodically strike the snow and ice on the road[19], separating the snow and ice from the road with the impact. But the efficiency of this method is lower, the road can be easily damaged, and certain auxiliary systems are required, so it has not been actively promoted. Mechanical clearing method currently is the snow clearing method mainly applied in foreign countries. As it is a flexible multi-purpose machine, can realize long-distance transportation of snow and ice, has higher efficiency, and essentially has no damage and pollution to vegetation and environment, this snow clearing method is developing rapidly abroad. The main models are Unimog, Multiear and SK150, and the representative production companies are SCHMIDT company in Britain, DAIMLER-BENZ company in Germany and MARCEL-BOSCHUNG company and VOLKSWAGEN company in Switzerland[17].

Germany mainly produces snow clearing machinery of snow plow and rotor, and applies vehicles, special locomotives, construction vehicles and other machinery as the motor vehicles of snow clearing machinery. Germany also develops professional road machinery qualified with the functions of sweeping road, scrubbing fence signs and clearing the new snow on the road[1]. KO-812-2 snow clearing machinery is a new product developed by Russia, its motor vehicle is MT3-80 / 82 tractor, the work equipment equipped are disk brush, coulter and bulldozing plate, and its functions are removing trash, snow and sand pile, so it can be used to clear snow on streets, sidewalks and highways [6]. Snow clearing machinery developed in Japan has a high technical level, and snow clearing of road had applied the method of installing V-shaped plow on truck as early as 1943. According to data, there were 45,678 units of snow clearing machinery produced by Japan in 2007, the main snow clearing machinery products have a high versatility[7], and the design emphasizes the accessory for mounting snow shovel and the comfort of cab, solving the problems of large amplitude of swing and serious bumping in the operation process. It also has the advantage of changing the side discharge mode of snow and ice through actual working mode, greatly facilitating the work condition of the machinery, and the design in job performance and drivers' horizon also have reached a higher level. Canada has specialized road snow clearing institutions which are equipped with professional snow clearing machinery, and road weather systems are installed on the main roads, to efficiently allocate snow clearing machinery, efficiently and promptly clear snow and ice on the roads. And it is stipulated that the snow must be eliminated once reaching 5 mm.

Mechanical snow clearing technology in China began in the late 1970s, and research and production units are mostly concentrated in the three northern regions with heavy snowfall in the winter [4,8,12,13,20,22]. Snow clearing machinery are mainly snow shovel, spiral snow blower and sweeper, and the techniques mainly originate from abroad, so they are relatively mature. Chinese research on the clearing technology of solid snow started relatively late. Li Qiaofei and Wu Hongshan of Jiamusi University successively developed JD-ShX3200 snow removing machine and disc rolling and straight cutting snow clearing machine since 2001[14]. In 2005, Ma Wenxing, Deng Hongchao, et al. of Jilin University conducted an in-depth study on the working mechanism and parameter optimization of multi-functional snow clearing machinery, and developed a rolling stone multi-functional snow removing vehicle, and its key component, rolling stone, is specifically designed for compacting snow [18]. In 2007, Shao Junpeng, et al. of Harbin University of Science and Technology conducted an in-depth study on the mechanism and parameter optimization of vibratory snow clearing[23]. Currently, China have developed snow removing equipment of various principles and types that are put into use, such as CBX-216 comprehensive icebreaking and snow clearing machinery developed by Harbin Forestry Machinery Research Institute, ZH1200 combined-type icebreaking and snow clearing machinery developed by Cheng Xianchun of the School of Mechanical Engineering, Changchun University, CB1500 compacted snow clearing machinery jointly developed by Jilin University and Highway Machinery Plant of Jilin Province, "No.4 Snow Wolf" ice removing machinery developed by Harbin Snow Wolf Snow Clearing Machinery Co., Ltd., ZL50G vibratory roller deicing loader produced by XCMG [5,11].

Although many domestic research and development units have done a lot of work on the development and technology introduction of snow clearing machinery, but so far, professional snow clearing machinery still have not been promoted and used in a large scale, and the main reasons are as follows.

(1) Compared with foreign snow clearing level, the operating speed of domestic snow clearing machine is slow.
(2) The protection of mechanical snow removing on the road is poor, and when the roads are rugged, the operation of snow clearing machine will cause damage to the roads.
(3) The utilization rate of the machine is low, while the cost is high. Professional snow removing machinery are mostly medium-sized, and they can only be used for snow removing, so the machines are idle during most of the year, greatly increasing the cost of snow removing machines. Thus, many places still select artificial snow removing, which not only wastes a lot of manpower, but also affects the speed and quality of snow removing.
(4) The avoidance function of the currently used snow clearing device is not ideal.

Compared with other types of snow clearing machines, snow clearing machine of snow throwing type is generally qualified with the functions of snow cutting, collecting, pushing, moving and throwing, which has broader application scale and is a modern, efficient snow removing machine. Since the 1980s, it has gradually been widely used in Northern America, Northern Europe and Hokkaido region of Japan. Large-scale icebreaking and snow clearing vehicles still can be observed in some areas of China, but most are pushing type. Advanced throwing type is much less, while the price is high, and the maintenance is inconvenient for it is an imported product. The corresponding small-scale products applied for snow clearing of enterprises, urban secondary roads and sanitation personnel are rarely seen. Domestic studies in this regard are few, and domestic manufacturers producing small-scale snow clearing machine of throwing type are rare. Centrifugal icebreaking and snow clearing system differs from conventional icebreaking and snow clearing device in that it changes the traditional icebreaking ways of rolling and plowing. Instead, it applies new ice-breaking mode - centrifugal percussion icebreaking, which meets the mechanical feature that the plane generates a greater impact while suffering an instantaneous impulse (in the instant of percussion, the hammer is in contact with the ice surface, so the impact on the ground is very small). And the spring installed inside ice-breaking knife can protect the ground well when the road surface is not flat. Centrifugal icebreaking and snow clearing device has compact structure, light weight, excellent performance, and is easy to use; can be applies to cope with natural disasters caused by snow and ice; has strong adaptability to the road environment; compared with foreign snow removing equipment, has reasonable price, simple operation and easy maintenance. Thus, study, design and development of small snow clearing machines certainly have great market prospects. Therefore, the research, design and development of small-scale snow clearing machine definitely have great market prospects.

3. System structure design

The schematic diagram for the general assembling of ice breaking and snow removal system is shown in Fig. 1. In the front of vehicle, there are ice and snow shovels, snow blowers and centrifugal ice breaking unit; on the top of the vehicle, the motor and reducer are installed; the complete machine applies four wheels to walk, thereinto, the front wheels are universal wheels and the back wheels are fixed wheels and the bearing bracket of the transmission of the complete machine is also installed on the vehicle. The driving power can be provided by the gasoline engine or manual work. For the convenience of operation, the handrail is used to control the trolley direction and the control buttons of the motor are installed on the two handrails for the convenience of control.

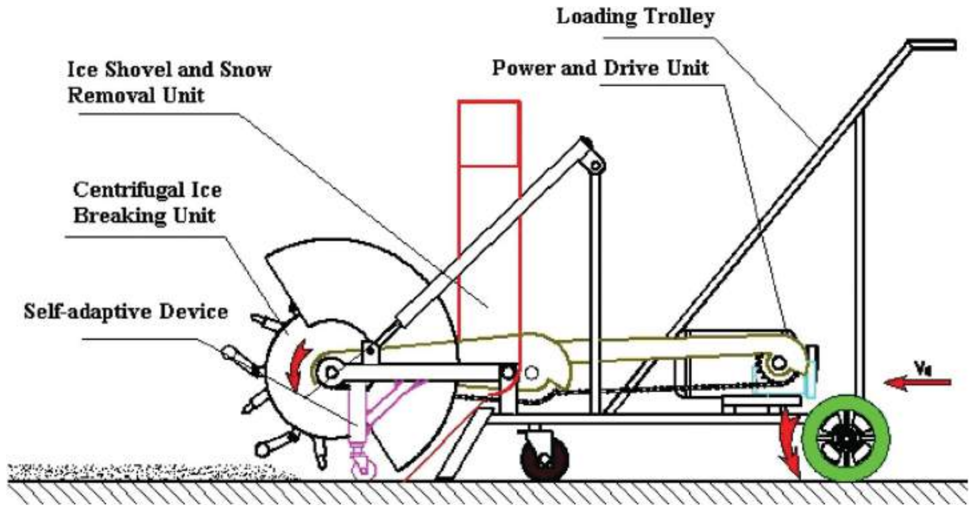

Figure 1. Schematic Drawing for Prototype of Centrifugal Ice Breaking and Snow Removal System.

3.1. Design on centrifugal ice breaking mechanism

The centrifugal ice breaking mechanism is the core work unit of the ice breaking and snow removal system and its structures include the centrifugal hammer, self-adaptive ice chisel and centrifugal drum. The ice breaking hammer obtains certain speed through the rotation of rotation trundle by transmission mechanism; when the centrifugal mechanism touches the ice layer, the centrifugal hammer hits the ice layer firstly and then the self-adaptive ice chisel drills the ice so that the ice layer will rupture in order to realize ice breaking. The schematic diagram for the principle of centrifugal ice breaking mechanism is shown in Fig. 2. Since the centrifugal mechanism has two degrees of freedom, the motion form will change after the centrifugal hammer hits the ice layer instantaneously and thus it will not cause destruction on mechanism and pavement. In order to reduce the mutual destruction between ice chisel and pavement during the drilling process and adapt to the rugged ice surface, the ice chisel has certain adaptivity. The self-adaptive ice chisel

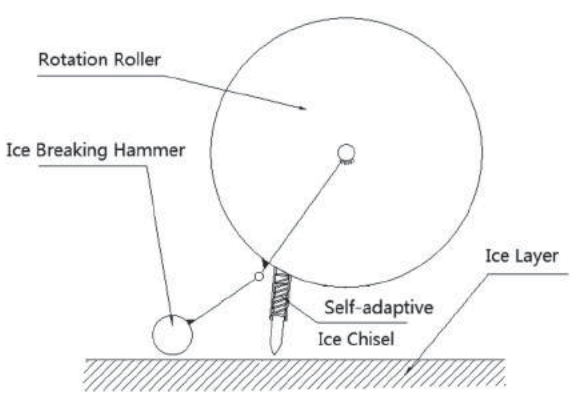

Figure 2. Schematic Diagram for Principle of Centrifugal Ice Breaking Mechanism.

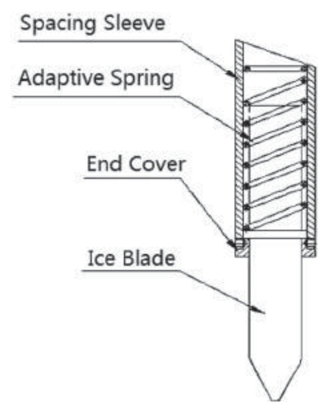

Figure 3. Structure Diagram of Self-adaptive Ice Chisel.

is composed of ice blade, spacing sleeve and adaptive spring, as shown in Fig. 3. Fig. 4 is the schematic diagram for the structure distribution of centrifugal mechanism. Fig. 5 is the three-dimensional Effect Picture of Centrifugal Icebreaking Unit

3.2. Theoretical calculation of icebreaking striking force

Icebreaking hammer is to use rotary motion to get centrifugal force to strike the ice layer, and because centrifugal hammer is component of second degrees of freedom, and it gives an instantaneous force to the ice layer by the momentary impulse in contact with the ice layer, as long as centrifugal speed of centrifugal hammer is appropriate, it will not cause damage to the components and the road. It can be known from the theoretical analysis on centrifugal parameters that the momentary impulse of icebreaking hammer of a certain revolving speed hitting the ice layer is related to the quality of centrifugal hammer and the rotation point of the distance between centroids. In

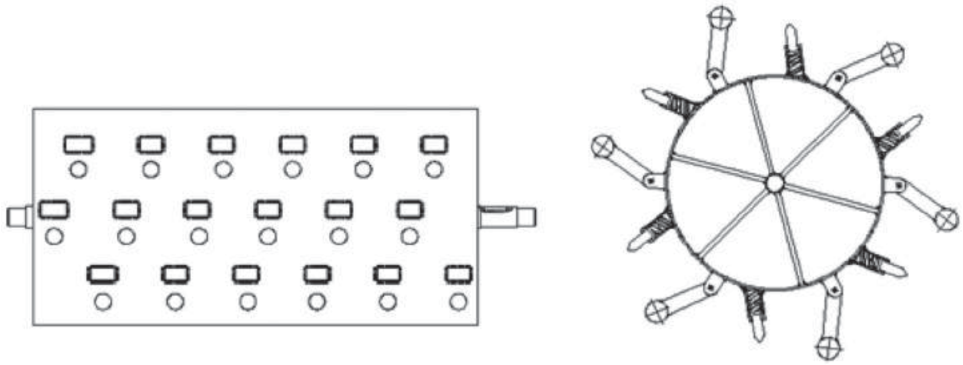

Figure 4. Schematic Diagram for Structure Distribution of Centrifugal Mechanism.

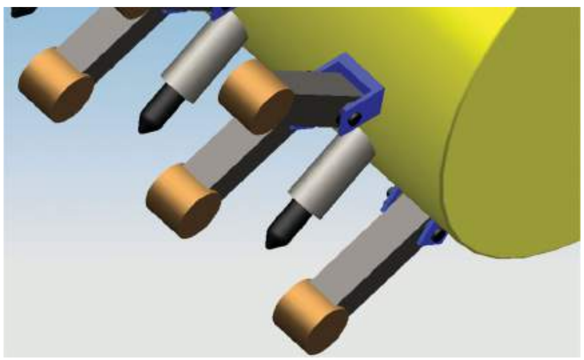

Figure 5. Three-dimensional Effect Picture of Centrifugal Ice-breaking Unit.

order to make centrifugal hammer have better percussion effect and have no damage to the component itself and the road surface, and in order to prevent too large angle between the centrifugal hammer in the work process and the ice layer that may cause damage to the component in the impact, it needs a stop means. The structure is shown in Fig. 6, and the three-dimensional appearance is shown in Fig. 7.

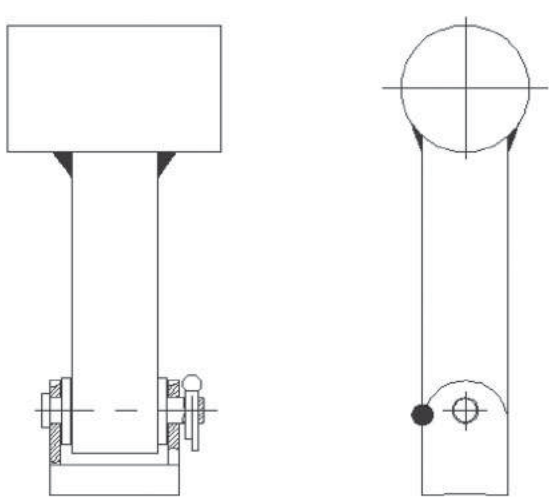

Figure 6. Schematic Diagram of Centrifugal Hammer.

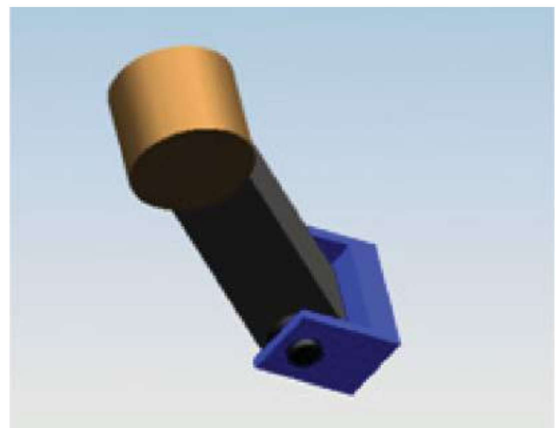

Figure 7. Three-dimensional Sketch of Centrifugal Hammer.

Given that the quality of ice breaking hammer is m and rotational speed of rotation trundle isω, the knocking is shown in Fig. 8.

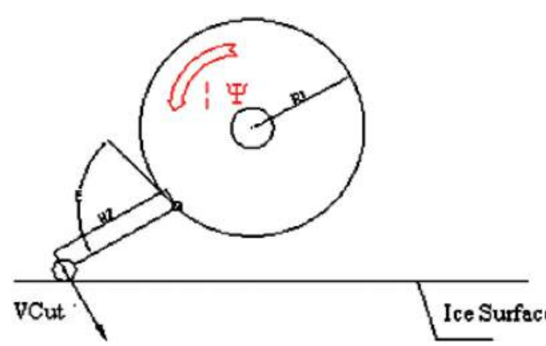

Figure 8. Schematic Diagram of Knocking Process.

R_1: radius of rotation trundle; R_2: length of ice breaking hammer; V_{cut}: the tangential velocity between the barycenter of the nutation of the ice breaking hammer and the center of gyration; θ: the intersection angle between the ice breaking hammer and the tangent of gyration center.

According to the principle of conservation of energy, it is obtained:

$$Ft = mv_1 - mv_0 \tag{1}$$

(supposing that the knocking energy is absorbed by the ice layer, that is $v_0 = 0$)

$$v_1 = Ft/m \tag{2}$$

The force for knocking and destroying the ice layer of H thickness is F; if it is known, the minimum velocity v_1 of knocking hammer during knocking and destroying can be obtained.

$$\mathrm{L} = \sqrt{\mathrm{R}_1^2 + \mathrm{R}_2^2 + 2\mathrm{R}_1 R_2 \cos\theta} \tag{3}$$

$$\mathrm{V}_{cut} = \mathrm{L}\omega \tag{4}$$

In the formula: L means the distance between ice breaking hammer and center of gyration.

$$\theta = 1.343 + \arcsin(1 - 0.0234\mathrm{R}_2/\mathrm{R}_1) - \arcsin(\mathrm{R}_2\cos\theta/\mathrm{L}) \tag{5}$$

From formula (3), (4) and (5), it is known that the speed of the tangential direction of the ice breaking hammer is related with the rotate speed of rotation trundle ω and the distance between hammer center and gyration center L and also the length of L has function relationship with the intersection angle between ice breaking hammer and tangent of rotation trundle. Then we can come to a conclusion that there is function relationship between the ice breaking hammer's linear velocity V_{cut}, rotate speed ω, R_1 and R_2 and the size of V_{cut} can be affected by the other three variables.

3.3. The design on ice shovel and snow removal mechanism and self-adaptive system

The ice shovel and snow removal mechanism is used to clean the crushed ice and snows and prevent secondary backlogging. In order to guarantee the ice and snow removal effect, the plough and winch ice breaking and snow removal are applied. When deicing, the crushed ice can be pushed to the side of the road; when removing snow, the snow can be collected timely and then winched to the roadside through the snow blower. The appearance is shown in Fig. 9.

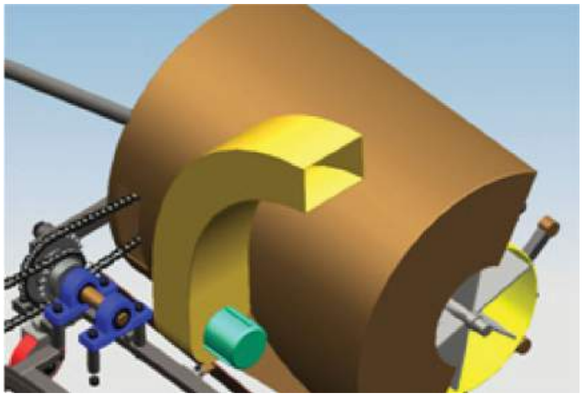

Figure 9. 3D Effect Drawing of Ice Shovel and Snow Removal unit.

The varying thicknesses of ice layers and rough road may cause poor effect of icebreaking and snow clearing device and also bring shake of device.In order to adapt to different pavements and ice layers of different thicknesses, the self-adaptive system is designed, which is mainly composed of self-adaptive frame and pre-loading device. The universal wheel on the lower end of the self-adaptive frame can keep in touch with the ice layer in real time and adapt to the pavement of certain angle; the pre-loading device can provide the self-adaptive frame with pretightening force in real time to guarantee the smooth working. The appearance is shown in Fig. 10.

Figure 10. 3D Effect Drawing of Self-adaptive System.

3.4. The design on transmission mechanism

In order to guarantee the good ice breaking effect of centrifugal ice breaking mechanism on the ice layer, the proper angular velocity should be provided for the centrifugal mechanism. In this design, the rotate speed of the drive motor is transmitted to the centrifugal ice breaking unit through the transmission mechanism. The transmission mechanism is mainly composed of the drive motor, reduction gear, transmission mechanism and rotation trundle. The diagram and 3D schematic diagram for the transmission of centrifugal mechanism are shown in Fig. 11 and Fig. 12 respectively.

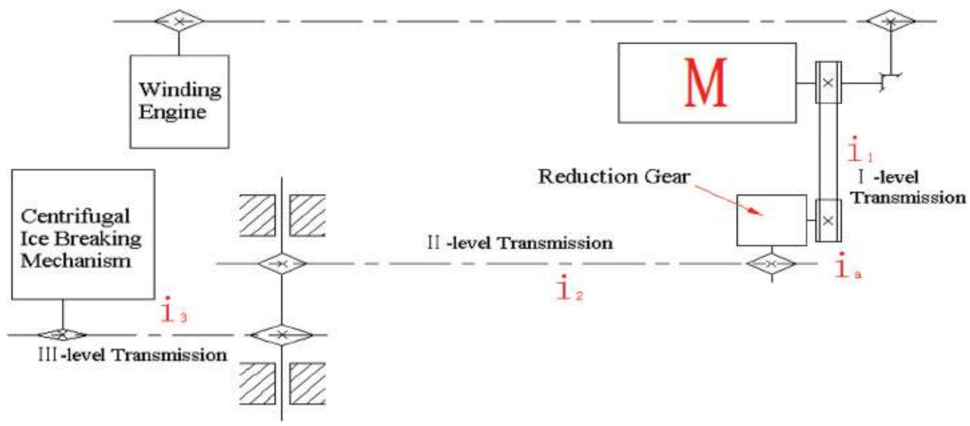

Figure 11. Diagram for Transmission of centrifugal mechanism.

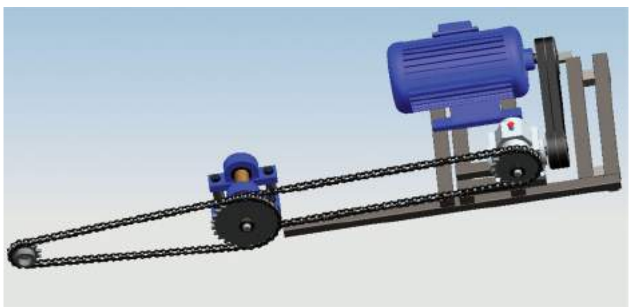

Figure 12. 3D Schematic Diagram for Transmission of Centrifugal Mechanism.

The overall ratio of transmission mechanism:

$$i = i_1 \times i_a \times i_2 \times i_3 = 1 \times \frac{1}{20} \times 1 \times 2 = \frac{1}{10} \qquad (6)$$

Thereinto, i_1— transmission ratio of I-level belt; i_2— transmission ratio of II-level chain; i_3— transmission ratio of III-level chain; i_a—speed ratio of reducer.

Driving motor is to provide power for the rotation of centrifugal mechanism, and Fig. 13 is a picture of motor. The selection of driving motor: revolving speed is 1400 *r/min*, rated power is 1.5KW, voltage is 380 V/50 Hz, and model is Y90L-4. When the revolving speed output by driving motor is 1400 *r/min*, if it is directly linked to the de-icing device, the centrifugal force generated by centrifugal knocking hammer is too large, causing damage to the institutional body and road surface. Therefore, a reducer is needed to reduce the revolving speed, so as to get an ideal effect. Reducer is shown in Fig. 14. The selection of reducer: WD type is center distance of 33, modulus is 2 and speed ratio is 1:20.

Figure 13. Picture of Motor.

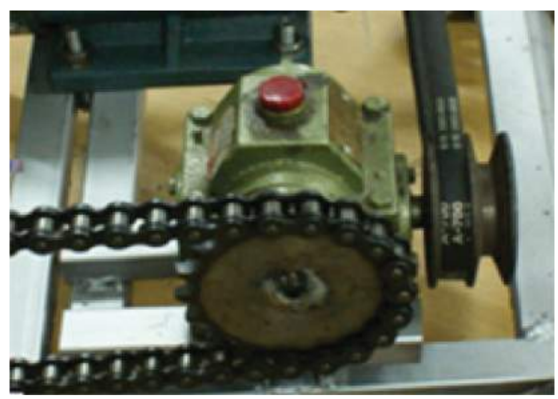

Figure 14. Picture of Reducer.

4. Check on important parts

During the operation of the system, the transmission shaft plays an important role in the power transmission. If the design is improper, the parts may deform and even rupture due to the large load, which may influence the smooth operation of ice breaking and snow removal. Hence, the rigidity and strength of these parts should be checked.

4.1. Check on axle strength

The sprocket shaft force of ice and snow remover is shown as Fig. 15. Through the force analysis on axis, it is obtained that [16,19] the transmission shaft of the ice

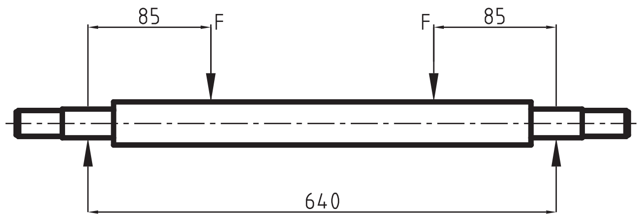

Figure 15. Force Diagram of Axles.

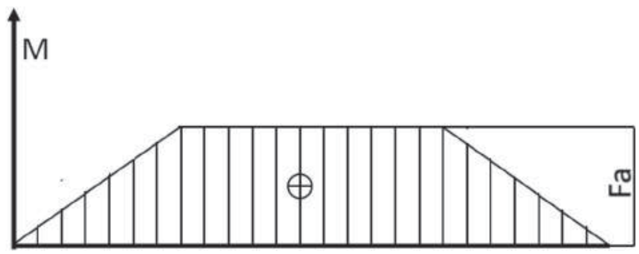

Figure 16. Moment Curve of Vehicle Wheel.

and snow removal system is affected by the supportiveness of the ground surface and the gravity of the vehicle. This axle is affected by bending moment and the moment curve is shown as Fig. 16. It is known that the dead load of the ice and snow remover is 62.5 kg. The ice and snow remover has four supporting wheels and the force of the supporting wheels can be considered as equivalent after balance weight. F = 13.125 kg, and the axle diameter is $d_{\min} = 30\text{mm}$, and the material is 45# steel. We can make verifying calculation on axle simplification.

Because

$$|\mathrm{M}|_{\max} = Fa = 13.125kg \times 9.8\,N/kg \times 85mm = 10.933N \cdot \mathrm{m} \quad (7)$$

The sectional dimension acquired by strength condition:

$$\mathrm{W_Z} \geq \frac{\mathrm{M_{max}}}{[\sigma]} = \frac{10.933N \cdot m}{40 \times 10^6\,N/m^2} = 2.7 \times 10^{-7} m^3 \quad (8)$$

Section Modulus in Bending

$$W = \frac{I_z}{y_{\max}} = \frac{\pi d^4/64}{d/2} = \frac{\pi d^3}{32} \quad (9)$$

So

$$\frac{\pi d^3}{32} \geq 2.7 \times 10^{-7} \mathrm{m}^3 \quad (10)$$

It is obtained $\mathrm{d} \geq 0.014m$

Through the above checking calculation, it is obtained that the design of the rear axle shaft of the ice and snow removal meets the strength condition.

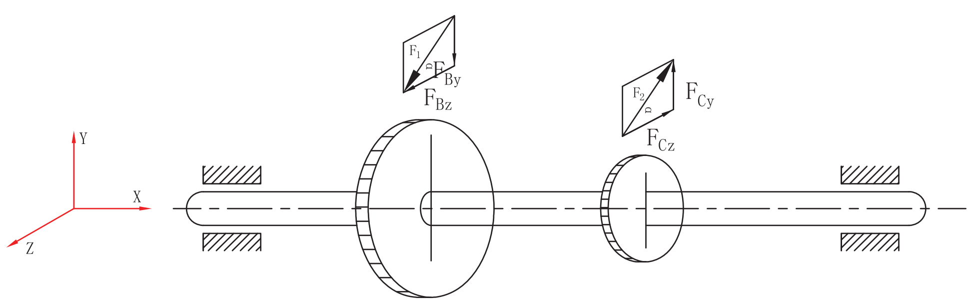

Figure 17. Force Diagram of Sprocket Shaft.

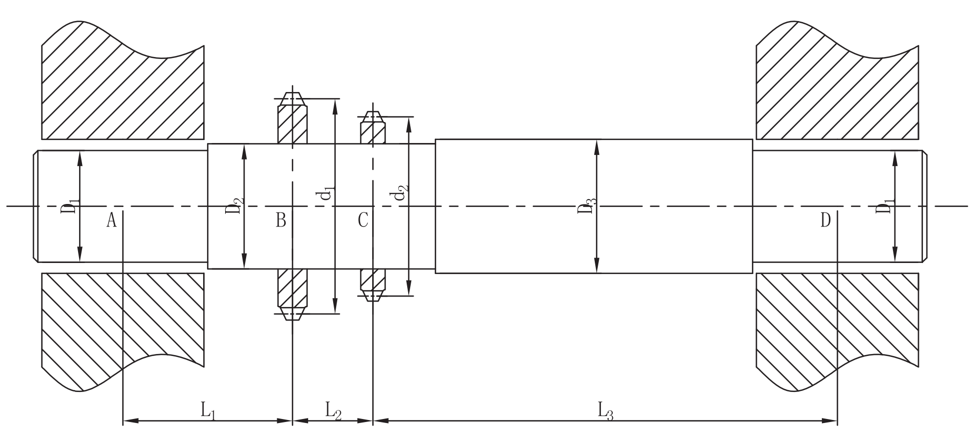

Figure 18. Simplified Force Diagram of Sprocket Shaft.

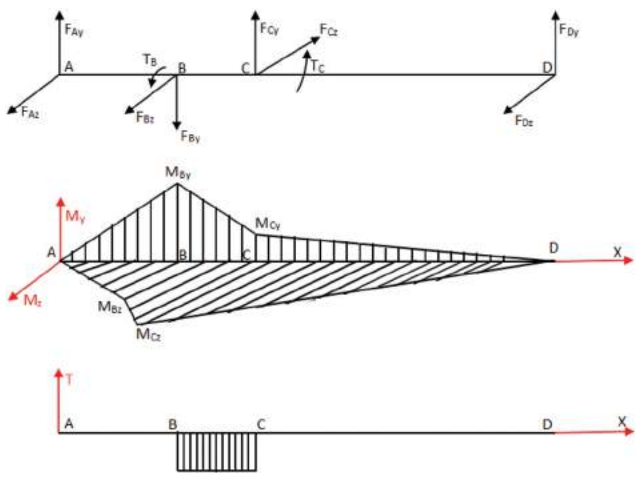

Figure 19. Force Analysis Figure of Sprocket Shaft

4.2. Check on axle rigidity

According to the bibliography [21], it is known:

$$I_p = \frac{\pi}{32} d^4 = 7.95 \times 10^{-8} m^4 \tag{11}$$

It is obtained

$$\phi_{\max} = \frac{T}{GI_p} \times \frac{180}{\pi} = 1.07^{(0)/m} < [\phi] = 2.0^{(0)/m} \tag{12}$$

Through the checking calculation, the design of axle meets the rigidity requirement.

4.3. Check on flat key of output shaft

The output shaft of chain wheel and chain wheel is connected by the flat key and the diameters of input axis and the connecting axis are $d_1 = 25$ mm and $L_1 = 60$ mm. After referring to the Machinery Handbook [3], the C-type flat key is selected. 8×7×60 GB/T1095-1979 $T_1 = 36.02\, h = 7mm$

$$\sigma_P = \frac{2T \times 10^3}{Kld} = \frac{2 \times 36.02 \times 10^3}{3.5 \times 56 \times 25} = 14.7 < [\sigma_p] = 110MPa \tag{13}$$

The flat key meets the strength requirement.

4.4. Roller sprocket shaft checking

The size of roller sprocket shaft and the rotation position locating of the shaft are shown in Fig.17 and Fig.18. Suppose power delivered sprocket shaft is P(KW), the revolving speed is n(r/min), and the wrap angle of the chain drive is α. Force analysis is conducted on the sprocket shaft, and shaft mainly bears the supporting force of shaft and the engaging force between chain and sprocket. Take a spatial coordinate system 0xyz, and decompose the engaging forces F1, F2 of the chain into tangential and radial forces: F_{Bz} and F_{By}, F_{Cz} and F_{Cy}. Move the two tangential forces F_{Bz} and F_{Cz} to the center of sprocket wheel respectively, while additional moments T_B and T_C are generated, then

$$T_B = F_{Bz} \times \frac{d_1}{2} \tag{14}$$

$$T_c = F_{cz} \times \frac{d_2}{2} \tag{15}$$

The force analysis figure of sprocket shaft is shown in Fig.19.

From

$$T_B = T_C = 9550 \frac{P}{n} \tag{16}$$

get:

$$F_{Bz} = \frac{2T_B}{d_1} \tag{17}$$

$$F_{Cz} = \frac{2T_C}{d_2} \tag{18}$$

Then, the intersection angle between engaging force and the direction of Z axis $\theta = 90\text{-}\alpha/2$, namely,

$$F_{By} = F_{Bz} \tan\theta \qquad F_{Cy} = F_{Cz} \tan\theta \tag{19}$$

From the balance equations of force and moment, get:

$$F_{Ay} = \frac{F_{By}(L_2 + L_3) - F_{Cy}L_3}{L_1 + L_2 + L_3} \tag{20}$$

$$F_{Dy} = \frac{F_{By}L_1 - F_{Cy}(L_1 + L_2)}{L_1 + L_2 + L_3} \tag{21}$$

$$F_{Az} = \frac{F_{Cz}L_3 - F_{Bz}(L_2 + L_3)}{L_1 + L_2 + L_3} \tag{22}$$

$$F_{Dz} = \frac{F_{Cz}(L_1 + L_2) - F_{Bz}L_1}{L_1 + L_2 + L_3} \tag{23}$$

thus,

$$M_{By} = F_{Ay}L_1 \qquad M_{Cy} = F_{Ay}L_1 - (F_{By} - F_{Ay})L_2 \tag{24}$$

$$M_{Bz} = F_{Az}L_1 \qquad M_{Cz} = F_{Az}L_1 + (F_{Az} + F_{Bz})L_2 \tag{25}$$

And then, substitute value into:

$$M = \sqrt{M_y^2 + M_z^2} \tag{26}$$

get the synthetic bending moments of sections B and C are respectively:

$$M_B = 193N \cdot m$$
$$M_c = 293N \cdot m$$

It can be seen that the synthetic bending moment of section C is maximum. And it can be observed from the moment diagram that the moment existing simultaneously is $T = 360N \cdot m$

For shaft made of plastic material, the third or fourth strength theory should be applied for calculation, and the calculation of formula.

$$\sigma_{r3} = \frac{\sqrt{M_c + T^2}}{W_z} = 28.4MPa \tag{27}$$
$$\sigma_{r3} < [\sigma] = 40MPa$$

shows that the intensity of the roller sprocket shaft meets design requirements.

5. ADAMS simulation and optimization analysis on centrifugal ice breaking mechanism

Centrifugal icebreaking and snow clearing system is a practical engineering machine, and in the design process, we should fully consider the characteristics of snow and ice and conduct analysis of rationality on its working principle. Therefore, the simplification of component design on the basis of realizing the function is required. In the design analysis process, modern mechanical design software like UG, Pro/E and Auto CAD are fully used to conduct aided design, and design optimization and dynamic simulation analysis are conducted on the model machine by virtual prototyping technology and ADAMS dynamic simulation software, thus greatly improving the design efficiency and design quality.

In order to guarantee the feasibility of the designed machinery and the smooth operation of the machinery during the process for knocking the ice layer, the ADAMS software is used to make the 3D simulation model during the design process[10,9], as shown in Fig. 20. The data acquired through simulation are used to optimize the structure design, which improves the design efficiency.

In order to check whether the knocking force of ice breaking hammer meets the design requirement during the knocking process, the ADAMS software is used for the theoretical analysis in the absence of physical during the pre-design phase, as shown in Fig. 21. It can be seen from the curve that during the initial stage of driving, the ice breaking hammer acquires strong power and the function transforms well during the stable process for knocking "ice surface". From the extreme higher position to the extreme lower position of the curve, it is the force of the hinge of the ice breaking hammer; on the side, it is the opposite force of ice breaking hammer; they two are equivalent force. It is observed that the force of ice surface during this process is extremely large and during the stable process, $F \approx 240N$, which meets the design requirements.

6. Replication experiment

In order to simulate the feasibility of the principle of centrifugal ice breaking and snow removal system, a simple model is made to simulate the working condition of an ice breaking hammer in the ice breaking unit, as shown

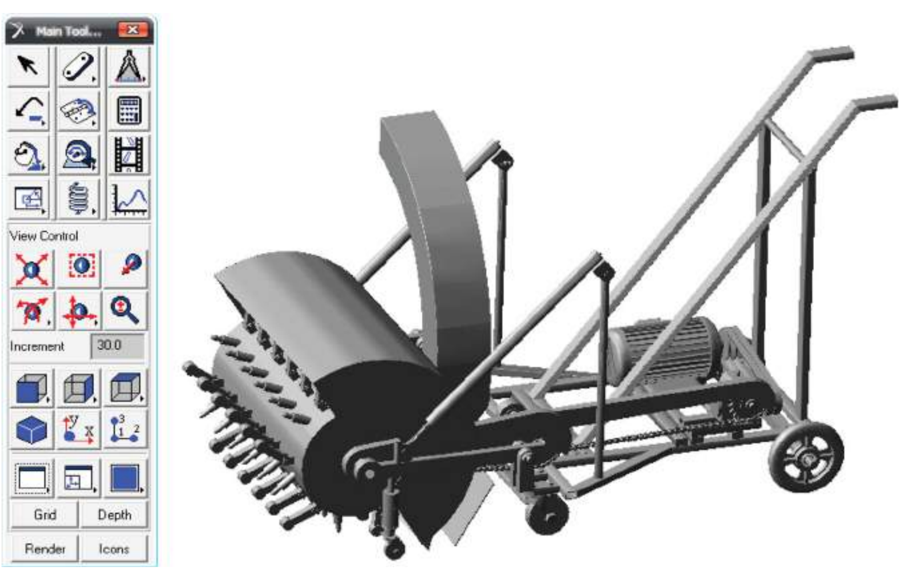

Figure 20. Physical Simulation Model through ADAMS.

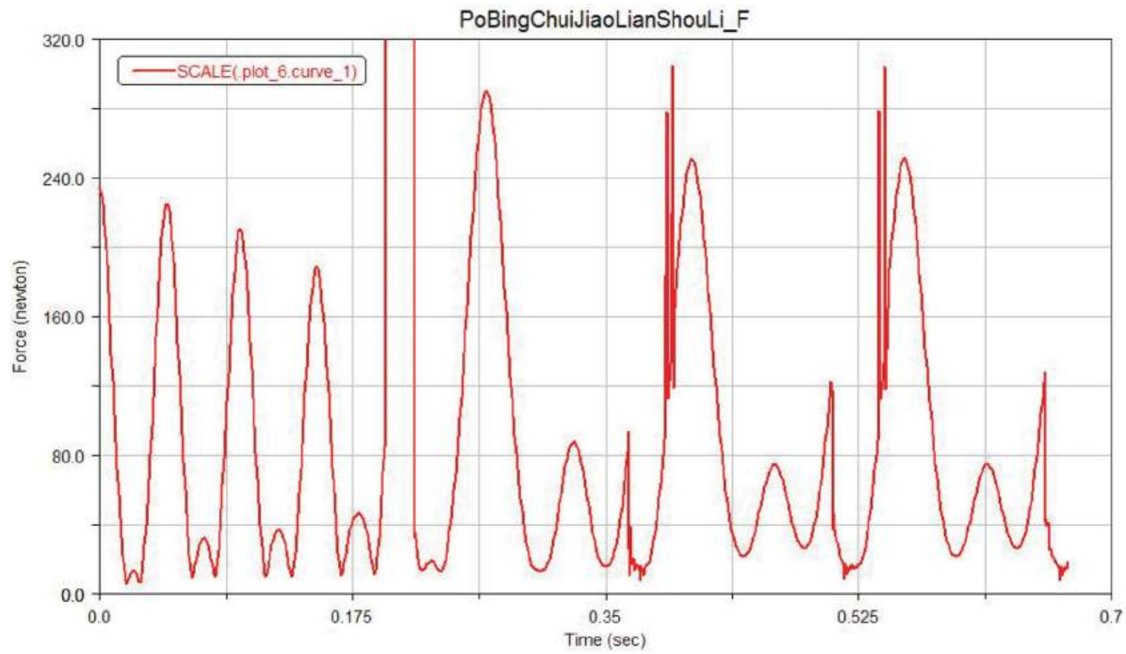

Figure 21. Force Analysis on Hinge of Ice Breaking Hammer.

Figure 22. Ice Breaking and Snow Removal Experiment.

in Fig. 22. The experimental facility is composed of a rotation trundle and an ice breaking hammer and the diameter of rotation trundle is 200 mm, the length of ice breaking hammer is 80 mm and the weight is 0.15 kg. The manual rotation is applied in this experiment with the average rotation speed of 120r/min. The experimental environment is the icy pavement at -28° in winter and the thickness of ice layer is between 20 and 35 mm.

After the ice breaking hammer hits the ice layer twice or for three times, part of the ice layer will be shattered and the effect of ice breaking will meet the expected requirement.

7. Conclusions

In this thesis, a new centrifugal ice breaking and snow removal system is designed. This system applies the modular design and various functions can be realized through module replacement and thus the machining cost can be saved. Finally, we produce the small prototype of ice breaking and snow removal and its design, fabrication, installation and debugging all meet the requirements of analog process. The experiment results show that the overall performance and key technical indexes of the prototype all meet the design requirements with good ice breaking effect and it can get through a life channel rapidly during the snow and ice disaster in order to win the precious time for rescue operation. At the present, the ice and snow disasters occur frequently; therefore, this device will play an important role during the snow and ice disaster.

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