Journal of Engineering Mechanics and Machinery (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/jemm.2024.090201
ISSN 2371-9133 Vol. 9 Num. 2

Design study of a mobile snow and ice removal unit for low-rise buildings

Tao Sun*, Xingyuan Fan, Bo Quan

School of Mechanical and Electrical Engineering, Lanzhou University of Technology, Lanzhou, 730050, China

**Corresponding author: a885253198@163.com*

Keywords: Portable Roof Snow Removal Unit, Snow removal equipment, Mechanical design

Abstract: Roof snow removal is an essential task in places with high snowfall, such as Northeast China. The aim of this study is to design a movable roof snow removal device with a programme design for the characteristics of low houses. Through field investigation, key parameters such as house height and structural characteristics were determined, and the general scheme of the roller brush snow removal device was designed. The device adopts a triangular frame design, equipped with a roller brush height adjustment mechanism and a travelling system, which enables the rotation and telescopic adjustment of the roller brush in the process of snow removal. The design of the mechanical unit includes the overall frame design, adjustment system design, telescopic system design and transmission system design. Finally, the comprehensive performance of the device is verified by simulated environment test and dynamic simulation, and its application prospect in the field of roof snow removal is expected.

1. Introduction

Modern housing buildings mainly rely on reinforced concrete and metal structures. If the snow is not cleaned up in time, it may lead to structural damage and steel strength, and even the risk of collapse. The current snow removal mainly relies on manpower, with low efficiency and high labor intensity. In view of the large number of urban houses, there is an urgent need for efficient scientific and technological solutions. With the rapid development of science and technology, mechanical snow removal is expected to become the mainstream in the future, replacing the traditional artificial snow removal method. Therefore, this project is designed as a mobile snow removal device, which is the relevant technical route after the formulation: The technical route of the snow and ice removal device of the low-rise building of the tool room is analyzed in detail from four aspects: transmission system, adjustment system, telescopic system and simulation experiment:

1) Transmission system design: Type selection: According to the working needs of the device, electric, hydraulic or pneumatic transmission may be used. Electric transmission is suitable for places that require precise control, hydraulic transmission is suitable for high-power applications, and pneumatic is suitable for environmental protection and pollution-free requirements. Structural design: Design gears, chains, belts or other transmission components to ensure the stable transmission of

torque and speed. Friction loss, durability and maintainability should be considered. Control system: Design a suitable controller, such as a frequency converter or servo motor drive, to achieve accurate control and adjustment of the transmission system.[1]

2) Adjustment system design: Angle control: Through the adjustment mechanism driven by the motor or hydraulic cylinder, it ensures that the snow removal device can be flexibly adjusted to the best angle and cover the snow from various angles. Power regulation: Design an adjustable thrust or pressure system to adapt to different snow thickness and hardness. Feedback system: Install sensors, monitor and feedback work status in real time to automatically adjust working parameters.

3) Design of telescopic system: Telescopic mechanism: Design a telescopic arm or roller to adjust the length as needed to improve work efficiency and flexibility. It may use a connecting rod mechanism, hydraulic cylinder or electric expansion. Locking mechanism: Ensure the stability of the equipment during work and prevent safety problems caused by accidental scaling. Structural strength: Ensure that the expansion part can maintain structural integrity under extreme conditions.4. Simulation experiment: Static test: In the laboratory environment, static tests are carried out on various components and systems to verify their performance parameters, such as torque, speed, durability, etc. Dynamic Simulation: Use 3D software for virtual simulation, simulate operations under various working conditions, and optimize design and control strategies.

Therefore, the aim of this paper is to summarize the advantages and disadvantages of the research techniques of the sweeping tools and devices by discussing them in depth, and to propose improvement and optimization solutions. Through these research results, it is hoped that effective technical support can be provided for solving the problems of snow clearing and de-icing of short-story buildings, as well as providing a safer and more convenient environment for urban construction and residents' lives.

2. Scheme design of removable roof snow removal device

2.1 Overall program design of removable roof snow removal device

The overall design scheme of the mobile roof snow removal device is designed for low-rise houses in Northeast China. Because the height of the house is generally 3-4 meters, and most of it is a three-spire structure, the height of the eaves is about 2.2-3 meters, and the middle triangle is about 1 meter. Considering the height range of snow removal, the roller brush needs to be adjusted within a range of 3-4 meters, so the device is designed with an adjustable roller brush height. At the same time, in order to adapt to the spacing between rural houses, the bottom is equipped with a mobile system. The roller brush is cleaned back and forth through telescopic movement during the snow removal process to ensure cleanliness. The back of the roller brush is also equipped with an auxiliary cleaning device to further improve the snow removal effect (as shown in Figure 1).[2]

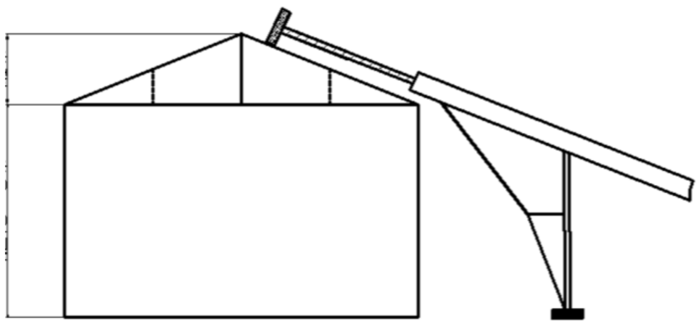


Figure 1: Schematic diagram of the snow removal status of the device

After comprehensively considering the working environment, snow removal height and cost-effectiveness, this project chooses a triangular frame structure, which includes a telescopic rod and a walking system. The rotation and expansion action of the roller brush are driven by a stepper motor. This design ensures the stability and flexibility of the device.

2.2 Mechanical unit program design for removable roof snow removal device

The mechanical unit design of the removable roof snow removal device is mainly based on the shape, distribution characteristics and snow removal requirements of the roof. For different roof conditions, the designed snow removal car needs to have a certain degree of adaptability. The following is the design of the key parts [3]

2.2.1 Overall frame design

Considering the snow removal environment and the size and weight of the equipment, we adopt a stable triangular shape. Considering that the height of the house is roughly similar but there are differences, the design includes a roller brush height adjustment mechanism, which is connected by a hinge mechanism, and the bottom is equipped with a walking system to adapt to the movement of various houses. In order to ensure stability, there is a locking mechanism near the hinge mechanism to prevent loosening during operation.[4]

2.2.2 Adjustment system design

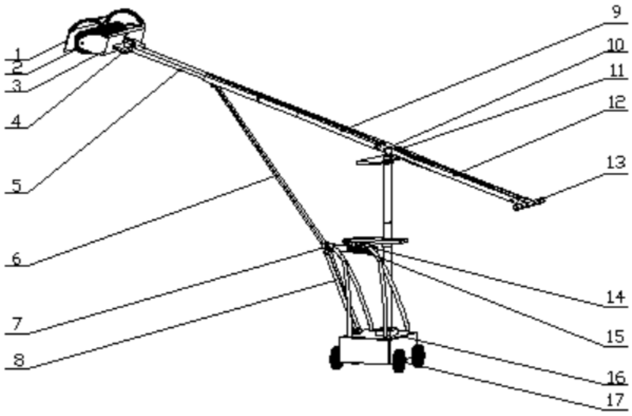
Roller brush height adjustment and expansion adjustment are the core. The height adjustment of the roller brush is set according to the height of the house. It is usually within 3-4 meters.[5] The angle of the roller brush is changed by adjusting the tension rod of the locking mechanism through the hinge mechanism and the locking mechanism. The expansion of the roller brush is achieved in one direction. When removing snow, the roller brush both rotates and expands in a straight line to ensure the complete removal of snow.

In short, this design fully takes into account various factors in practical application and aims to provide an efficient, flexible and adaptable mobile roof snow removal device.[6]

3. Structural design of removable roof snow removal unit

3.1 Overall structure of the removable roof snow removal unit

Mobile roof snow removal device can be adapted to different roof environments for snow removal work, the device mainly includes body travelling mechanism, locking mechanism, hinge mechanism, telescopic system and other major components, the overall frame adopts a triangular design, the bottom of the body is equipped with a travelling mechanism, the snow removal brush and telescopic rod is connected to the device above the position, and by the hinge mechanism is connected to the support, the hinge mechanism is connected to the adjusting rod, the adjusting rod is connected to the adjusting rod to ensure the stability of the whole device, the overall structural design is shown in Figure 2. One end of the hinge mechanism is connected to the adjusting rod, and the adjusting rod is connected to the locking mechanism to ensure the stability of the whole device, and the overall structural design of the movable roof snow removal mechanism is shown in Figure 2.



1.snow scraper; 2. snow scraping roller brush; 3. fixing device; 4. stepper motor; 5. extension rod; 6. connecting rod 3; 7. hinge; 8. connecting rod 2; 9. extension rod sleeve; 10. fixing sleeve; 11. stepper motor; 12. console; 13. handle; 14. connecting rod 1; 15. rotating rocker; 16. vehicle body; 17. wheels;

Figure 2: Overall structure diagram of movable roof snow removal device

3.2 Mechanical system design of a removable roof snow removal unit

The mechanical system of the snow removal device for low-rise buildings mainly includes four parts: the overall frame, the adjustment system, the telescopic system, and the transmission system.

3.2.1 Overall framework design

(1) Overall frame structure design

Snow removal device frame structure as shown in Figure 3, the elongated rod set is 4 metres long, there is a support rod at 1.7 metres from the right end point, the support rod and the elongated rod set can be seen as a lever system, the right side of the elongated rod set from the ground height of 1.7 metres, according to ergonomics principles, the height of this height and the majority of the population of the work of the appropriate height coincides with. At the other end of the elongated rod set connected to the lower end of the connecting rod 3, the bottom of the connecting rod 3 and the hinge mechanism to ensure the stability of the device to work, reduce the deformation of the whole rod under pressure. From the overall view of the whole frame is triangular, so that the whole device is more stable, the elongated rod length of 4.5 metres, in the rod set inlay installation, can extend the distance of 0.5-2 metres.

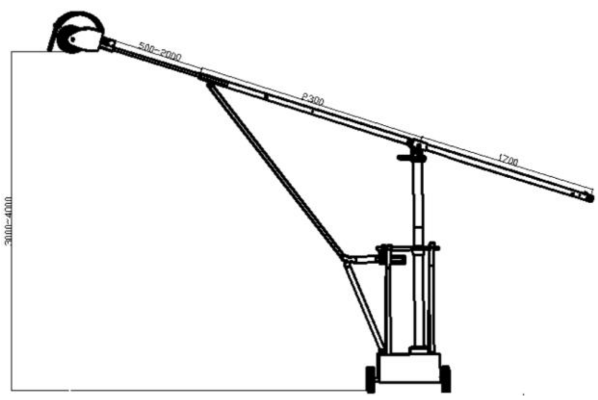


Figure 3: Schematic diagram of the overall framework of the movable roof snow removal device

(2) Design of snow removal brush structure

Combined with the development and structural changes of Sun Xiaoqiang's snow removal device [7] and the working condition of this device, this device adopts a cylindrical roller brush design, the snow removal roller brush bristles are made of flexible material in order to reduce the damage to the roof when removing the snow, the diameter of the roller brush is 25cm, the length of the roller brush is 75cm, and the schematic diagram of the snow removal roller brush is shown in Figure 4 and Figure 5.

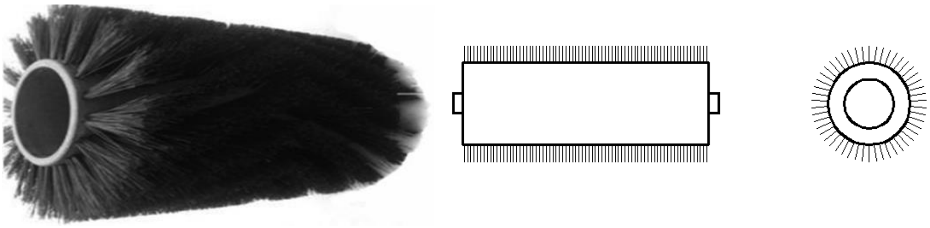


Figure 4: Roller brush structure

(3) Travelling mechanism design

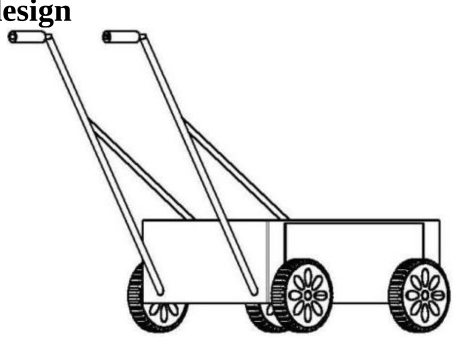


Figure 5: Schematic diagram of travelling mechanism

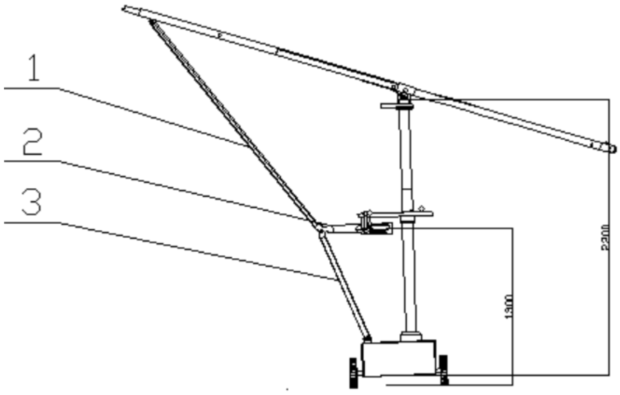
3.2.2 Conditioning system design

The height of the house is generally between 3-4 metres, so the working height of the snow-removing roller brush needs to be between 3-4 metres, and the adjusting mechanism is mainly to adjust the snow-removing height of the roller brush, which is mainly composed of the hinge mechanism and the locking mechanism.

(1) hinge mechanism

By simulating and optimising the dynamics of the electric rotary-driven double-hinged wing folding mechanism by Li Yuxiang et al [8], this device adopts the morphological characteristics of the folding mechanism, and the hinge mechanism of the device is designed, the double-hinged hinge mechanism is located in the middle of the snow removal device, and consists of three chain rods, link 1 is connected to connect with the locking mechanism; link 2 is connected to the bottom body; link 3 is connected to the elongated rod set, and the three rods Acting together on the same hinge, the connection with other parts are equipped with a rotating shaft.

Multiple hinge mechanisms are applied in the adjustment process of the fixed rod mechanism, and the adjustment is relatively easy. The height and angle adjustment of the fixed rod is shown in Figure 6.



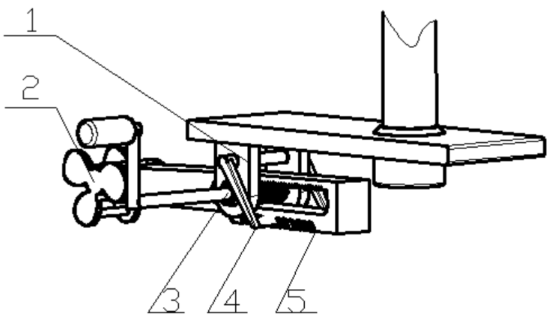
1. Connecting rod 2; 2. Connecting rod 1; 3. Connecting rod 3

Figure 6: Schematic diagram of the hinge mechanism

In the hinge mechanism, the connecting rod 1 can be moved laterally, and when the position of the rod 1 changes, the angle between the connecting rod 2 and the connecting rod 3 also changes, and the angle between the rod 2 and the rod 3 is set to be α. The height of the adjustable snow-removing roller brush can be adjusted to be the maximum value when the α is 180 degrees and the extension rod does not telescope inside the rod sleeve. The α of the connecting rod 1 has a small range of variation of about 20 to 30 degrees, for which the hinge mechanism adjustment is used as a height-assisted adjustment method.

(2) locking mechanism

According to the design of a new type of double pawl-driven toothed ratchet mechanism by He Quanmao et al [9], this device combines a ratchet mechanism with a rack and pinion mechanism, and the locking mechanism mainly consists of a locking buckle, a rotating rod, a connecting rod, a fixing member, and a rotating gear, and the connecting rod is the connecting rod 1 of the hinge mechanism, and the connecting rod is equipped with a rack at the rear of the connecting rod that engages with the gear, and the locking buckle at the lower part of the device is able to play a role in fixing and preventing the connecting rod 1 from falling off. The device is unstable, the locking mechanism is connected to the hinge mechanism, and the connecting rod 1 is rotated by the rotating rod to reciprocate in the transverse direction when in use; the specific schematic diagram is shown in Figure 7.

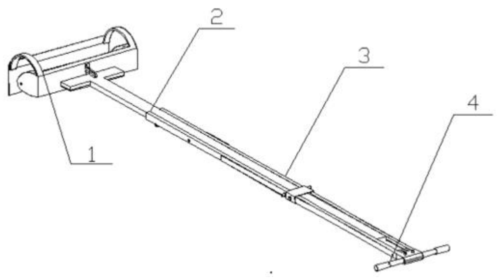


1. fixing; 2. hinge; 3. connecting rod 1; 4. latch; 5. rack

Figure 7: Schematic diagram of locking mechanism

3.2.3 Telescopic system design

According to the research and design of the telescopic mechanism of Wu Yicheng et al [10-11], the device needs the reciprocating motion of the roller brush in the direction of snow removal in order to maximise the efficiency when removing snow, and this process is mainly completed by the telescopic system, which adopts the form of linear motion, and mainly consists of the telescopic pole, the telescopic pole sleeve and other components, and is powered by the electric motor when it is in operation.



1.Snow removal roller brush; 2.Extension pole; 3.Extension pole sleeve; 4.Handle;

Figure 8: Schematic diagram of telescopic rod and rod sleeve inlay

3.2.4 Drive train design

The transmission system of the removable snow removal device mainly includes two parts: the brush rotation transmission and the brush expansion transmission, which are driven by their respective stepping motors.

(1) Roller brush rotary drive

Brush roller rotation is powered by a stepping motor, which drives the pulley to rotate, and then drive to the brush roller shaft after one level of transmission, and finally the brush roller shaft rotates to carry out the work.

$$N = \frac{60f}{p} \tag{1}$$

$$T = \frac{9550p}{n} \tag{2}$$

(2) Roller brush telescopic drive

Telescopic drive by the stepper motor to provide power, telescopic movement relative to the snow removal process is an auxiliary movement, to the process does not require too much speed, for this reason do not need to be particularly large power motor. When working by the motor will power transmission to the shaft 1 and then through the conveyor belt transmission to the shaft 2, the other end of the shaft 2 connected to the gear, elongated rod set with rack and pinion, the shaft 2 is fixed in the rod set, the gear drives the rack and pinion rotation and ultimately make the elongated rod in the rod set in the reciprocating retractable movement.

In order to reduce the manual processing precision is low, the cost of high deficiencies, device components are used in standard parts, the device in the diameter of the shaft is set to 30mm, the gear modulus is 1.5, the gear outer diameter of 68mm, after the 15mm, the use of nylon, the inner diameter of the bushing and the shaft to match the use of the outer diameter of 30mm, 50mm, 60mm, the depth of the groove is set to 13mm.

The device drive are used belt drive, belt type for v-type conveyor belt ordinary A-type belt (belt cross-section shown in Figure 9), the following is the specific calculation process.

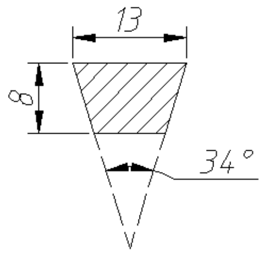


Figure 9: V-type normal A-type conveyor belt

1) Determine the calculated power P_{ca}

The working factor P_{ca} =1.1 can be checked from the mechanical design manual, so

$$P_{ca} = K_A P = 1.1 \times 1.1 KW = 1.65 KW \tag{3}$$

2) The belt type selected

According to the calculated power P_{ca} and small belt wheel speed n_1, the belt type of A-type groove is selected from the wheel groove cross-section size table.

3) Determine the reference diameter of the belt wheel d_{d1}

(a) The reference diameter of the primary small belt wheel d_{d1}

According to the belt type of the V belt, refer to the minimum reference diameter table of the V belt wheel and the reference diameter series table of the ordinary V belt wheel to determine the reference diameter of the small belt wheel $d_{d1} = 90\text{mm}$.

Check the belt speed v.

$$v = \frac{\pi d_{d_1} n_1}{60 \times 1000} = \frac{\pi \times 90 \times 120}{60 \times 1000} m/s = 0.57 m/s \tag{4}$$

Because 0.56m/s<0.57m/s<0.61m/s, the speed is appropriate.

Calculate the reference diameter of the large belt wheel.

$$d_{d1} = i d_{d1} = 2 \times 90\text{mm} = 180\text{mm} \tag{5}$$

According to the reference diameter series table of ordinary V-belt wheels, the standard value is d_{d2}=180mm.

4) Determine the center distance a and reference length of the V band

(a) According to the restrictions and actual requirements of the overall size of the belt drive, the initial center distance is $a_0 = 240\text{mm}$.

(b) Calculate the corresponding band length:

$$\begin{aligned} L_{d0} &\approx 2a_0 + \frac{\pi}{2}(d_{d_1} + d_{d_2}) + \frac{(d_{d_2} - d_{d_1})^2}{4a_0} \\ &= 2 \times 240 + \frac{\pi}{2}(90 + 180) + \frac{(180 - 90)^2}{4 \times 240} \\ &\approx 912 mm \end{aligned} \tag{6}$$

Choose the benchmark length of the band L_d=990mm from the benchmark length of the ordinary V-band.

(c) The actual center distance of the transmission a is approximately:

$$a \approx a_0 + \frac{L_d - L_{d0}}{2} = 240 + \frac{990 - 912}{2} = 279\text{mm} \tag{7}$$

Considering the manufacturing error of the belt wheel, the band length error, the elasticity of the belt and the need for supplementary tension caused by the relaxation of the belt, the range of the calculation center distance is 264mm to 539mm.

5) Check the corner of the small belt wheel α_1.

$$\alpha_1 \approx 180° - (d_{d_2} - d_{d_1}) \frac{57.3°}{a} = 180° - (180-90) \frac{57.3°}{279} \approx 161.5° > 120° \quad (8)$$

4. Conclusions

The snow removal device designed in this project is cheaper, simpler, easier to adjust and more efficient than previous devices. Moreover, the adjustment system of this device can freely adjust the height of the roller brush through the hinge mechanism and the locking mechanism to adapt to the different heights of the houses when removing snow, so as to achieve the purpose of the same device for removing snow from houses of different heights, and it can also make use of the travelling mechanism in the removable mechanism, which ensures that it has independent travelling ability between different houses, so as to achieve the design concept that different houses can also be used.

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