# Design of Snow Shovel Robot′s Structure and Hydraulic System

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## Abstract

**This There is heavy snowfall in winter in northern in China, and the road is covered with heavy snow. Due to the low efficiency of manual snow removal and the harsh working environment, traditional snow removal vehicles are prone to failure. In response to this problem, a set of snow removal robot snow shovel structure and hydraulic system were designed. The force analysis of the snow shovel structure was carried out to design the hydraulic system circuit. Finally, using AMESim system simulation software for simulation, the design requirements of the snow shovel structure are realized.**

## Keywords

**Clear snow robot, Hydraulic system design, AMESim simulation.**

## 1. Introduction

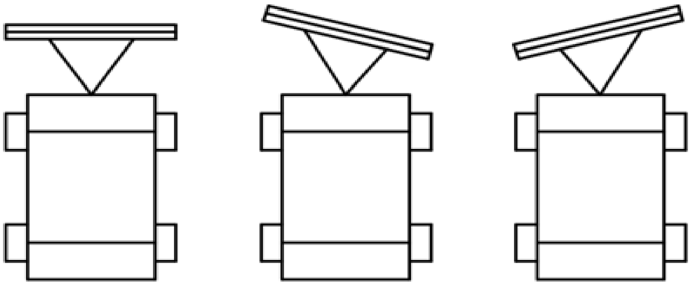
In winter in areas with long snow seasons in northern China, road snow accumulation has become a common natural disaster. The average occurrence rate of traffic accidents on the road due to snow is 4 to 5 times as usual. Clearing snow in time is an important and serious task for highway transportation authorities[1]. The design of the snow-removing mechanism is an important part of the design of the snow-removing robot system. The current mechanism mainly includes three types of rotating broom, snow blowing or snow-absorbing mechanism and snow shovel. The front of the robot is equipped with a front broom that can be tilted to either side, and its power is provided by a 37-horsepower Vanguard 61E gasoline engine[2]. The crawler snow blowing robot invented by German researchers blows snow to the roadside through a powerful fan[3]. The GPS autonomous navigation snow cleaning robot invented by researchers in Niigata, Japan sucks the snow into the machine and compresses it into rectangular ice bricks. The bricks are automatically neatly laid on the roadside[4]. However, the development and production of snow removal machinery in China is relatively late and is still in its infancy. Most winter snow removal in China uses a combination of manual, dump truck and salt spreader to remove snow. These snow removal methods have low efficiency and far lag behind developed countries Many snow removal equipment depends on imports and is expensive. Therefore, the snow shovel mechanism designed in this paper is an automatic and intelligent snow removal equipment because of its simple structure and low failure rate. It is the most commonly used snow removal mechanism[5]. This subject aims to optimize the structure on the basis of the existing snow clearing shovel mechanism, and quickly clear the snow to the side to complete the opening[6]. In addition, a hydraulic drive system was selected as the driving source, and a set of snow shovel hydraulic control system was designed. Finally, the AMESim system simulation software was used to simulate and analyze the snow blade hydraulic system[7].

The subject designs the snow removal robot to control the hydraulic system of the snow shovel device, and simulates and analyzes its hydraulic system based on the AMESim hydraulic simulation software to ensure that the hydraulic system can meet the needs of the snow shovel[8-16].

## 2. Design and Force Analysis of Snow-Shovel Robot Snow Shovel Device

According to the actual working conditions of the snow shovel, the snow shovel needs to have three different working positions. The first working position is shown in Figure 1(a). The snow shovel is in a horizontal position. In this position, when the snow shoveling operation is carried out, the snow will accumulate directly in front of the snow shovel. Push the snow shovel to the sides. The second working position is shown in Figure 1(b). The snow shovel deflects to the right. In this position, when the snow shoveling operation is carried out, the snow will be accumulated in a direction perpendicular to the snow shovel. After the degree, the snow shovel moves in the yaw direction, and the snow will be pushed to the right of the snow robot. The third working position is shown in Figure 1(c). The snow shovel deflects to the left. In this position, when the snow shoveling operation is carried out, the snow will also be accumulated in the direction perpendicular to the snow shovel. After a certain degree, the snow shovel moves in the yaw direction, and the snow will be pushed to the left of the snow robot.

The above three working positions can realize the snow-clearing work in different width ranges, and the width range is between 670~700mm.



(a) Horizontal angle (b) Swing to the right (c) Swing to the left

Fig.1 Schematic diagram of snow shovel deflection function

According to the actual execution needs of snow-shoveling robot pushing snow shovel, this article designs a snow pushing shovel actuator, which includes hydraulic shovel deflection unit and lifting unit, as shown in Figure 2.

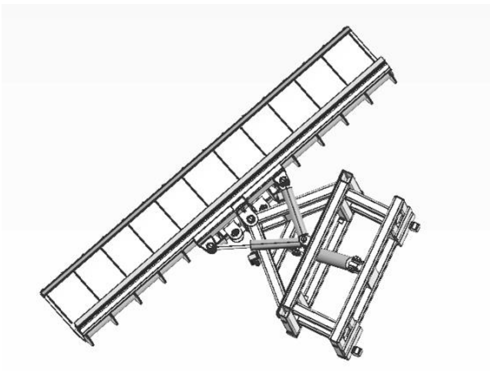


Fig.2 Structure of snow shovel device

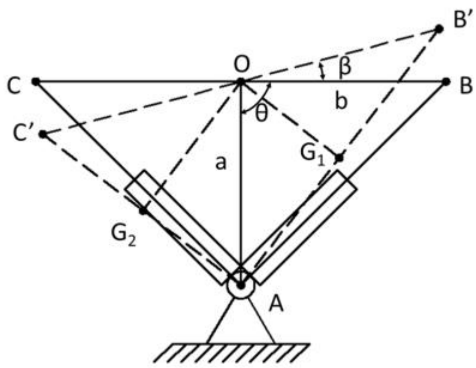



Fig.3 Schematic diagram of the force of the snow shovel deflection mechanism

According to the principle diagram of the snow shovel deflection device, it can be obtained from the cosine theorem, the stroke of the hydraulic cylinder is:

$$AB = AC = \sqrt{a^2 + b^2 - 2ab\cos\theta} \quad (1)$$

$$AB' = \sqrt{a^2 + b^2 - 2ab\cos(\theta + \beta)} \quad (2)$$

$$AC' = \sqrt{a^2 + b^2 - 2ab\cos(\theta + \beta)} \quad (3)$$

The arm $H_1$ of the hydraulic cylinder AB′ to the yaw center point O is:

$$H_1 = OG_1 = \frac{\text{ab}\sin(\theta+\beta)}{\sqrt{a^2+b^2-2ab\cos(\theta+\beta)}} \tag{4}$$

The arm $H_2$ of the hydraulic cylinder AC′ to the yaw center point O is:

$$H_2 = OG_2 = \frac{\text{ab}\sin(\theta+\beta)}{\sqrt{a^2+b^2-2ab\cos(\theta+\beta)}} \tag{5}$$

The driving torque of the yaw hydraulic cylinder measures the driving capacity of the snow shovel hinged yaw device. The driving torque is equal to the product of the force of the piston rod of the hydraulic cylinder and the force arm formed by the hydraulic cylinder relative to the center point of the yaw, Then the driving torque formula of the hydraulic cylinder in the snow shovel deflection device is as follows:

$$M = \frac{\pi P}{4}\left[D^2 H_1 + \left(D^2 - d^2\right)H_2\right] \tag{6}$$

In the formula: P-hydraulic system pressure, MPa; D-hydraulic cylinder inner diameter, m; d-piston rod diameter, m.

When the snow shovel of the snow removal robot works at a horizontal angle, there will be a large amount of snow accumulation in front of the snow shovel. According to experience and the size of the snow shovel, the maximum volume of snow in front of the snow shovel is about 0.00075m3. According to experience, the frictional resistance between the snow and snow shovel and the ground is relative to the maximum resistance torque of the snow shovel rotation center, that is, the formula of the maximum resistance torque of the hydraulic cylinder is:

$$M = \frac{1}{3}\left(F_{\text{arm } friction} + F_{\text{shovel } friction}\right)\frac{B}{4} = \left(\mu_1 \rho g V + \mu_2 G\right)\frac{B}{12} \tag{7}$$

Where: B-the axial length of the snow shovel, m; μ1-coefficient of dynamic friction between the snow and the ground, 0.03 to 0.2; Fn-the positive pressure N of the snow pushed by the snow shovel to the ground; ρ-snow Density (density of ice-water mixture), kg/m3; V-snow volume in front of snow shovel, m3; g-acceleration of gravity, 10N/kg; μ2-coefficient of dynamic friction between rubber shovel and concrete pavement below snow shovel, 0.3 ; G-the weight of the snow shovel device, N.

The snow shovel lifting movement is realized by a symmetrical hinge four-bar mechanism telescopically driven by the hydraulic cylinder in the middle, and the force when the snow shovel lifting mechanism works is shown in Figure 4.

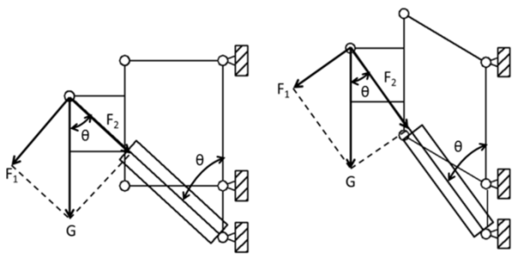



Fig. 4 Schematic diagram of the force of the snow shovel lifting mechanism

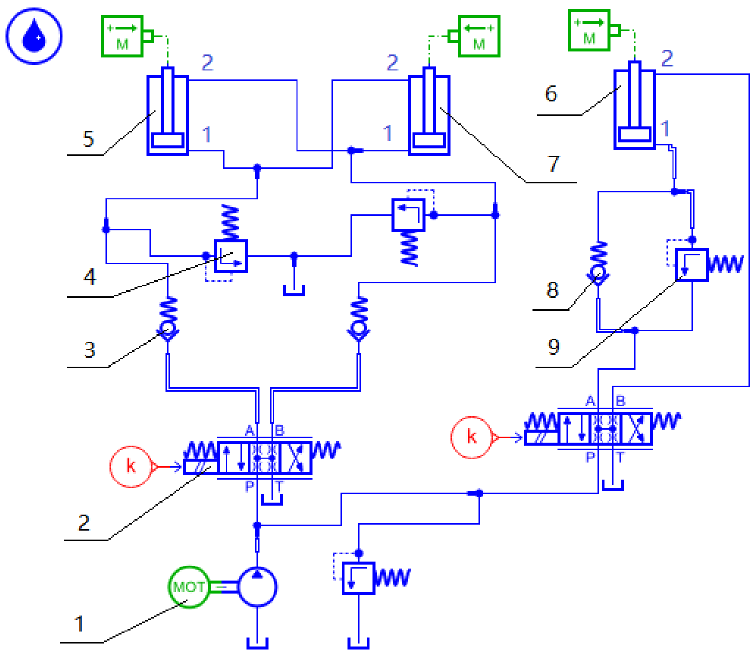
According to the load analysis diagram of the lifting hydraulic cylinder, the load of the lifting hydraulic cylinder is:

$$F = G * \cos\theta \tag{8}$$

In the formula: F2-the load N of the lifting hydraulic cylinder; G-the gravity N of the snow shovel device; θ-the angle of the lifting hydraulic cylinder axis relative to the ground normal.

## 3. The structure and working principle of the snow removal robot snow shovel hydraulic system

Use AMEsim simulation analysis software to model the snow removal robot snow shovel hydraulic system, as shown in Figure 5.




1-Hydraulic motor; 2-Electromagnetic directional valve for yaw circuit; 3-Bidirectional hydraulic lock; 4-Bidirectional buffer valve; 5-Oblique hydraulic cylinder 1; 6-Lift hydraulic cylinder; 7-Oblique hydraulic cylinder 2;

8-sequence valve; 9-lift loop bidirectional buffer valve

Fig. 5 Schematic diagram of the snow pusher hydraulic system

It can be seen from the schematic diagram of the hydraulic system of the snow shovel in FIG. 5 that the entire hydraulic system is divided into two parts, including: a snow shovel yaw hydraulic system and a snow shovel lifting hydraulic system.

The working condition of the sway system of the snow shovel: the hydraulic motor 1 drives the quantitative pump to provide hydraulic oil, and the electromagnetic directional valve 2 through the yaw circuit changes the flow direction of the hydraulic oil to control the extension and retraction of the yaw hydraulic cylinders 5, 7 To achieve the effect of yaw, in order to achieve the accuracy of the left and right position of the snow shovel, the yaw angle is measured by the angle sensor and the measurement signal is transmitted to the controller. After the controller calculates, the error compensation of the yaw angle is achieved.

The two-way hydraulic lock 3 and the two-way buffer valve 4 not only protect the oil path of the yaw hydraulic cylinder, but also play a role in controlling the execution speed of the hydraulic cylinder. This mode of action is the two-way hydraulic lock 3 and the two-way The buffer valve 4 changes the flow rate of the oil passage into and out of the actuator, thereby realizing the control of the actuator speed. The entire deflection circuit can deflect the snow shovel to a certain angle from left to right, and push the cleared snow to both sides of the snow removal robot. This deflection device can achieve the purpose of efficient snow removal.

The working condition of the snow shovel lifting hydraulic system: the hydraulic motor 1 drives the quantitative pump to provide hydraulic oil, and changes the flow direction of the hydraulic oil through the electromagnetic directional valve of the lifting circuit to control the ejection and retraction of the lifting hydraulic cylinder 6 to achieve the lifting effect. The lifting circuit can change the height of the snow shovel relative to the ground to adapt it to different road conditions. When the snow shovel is not working, adjust the extension length of the piston rod of the lifting hydraulic cylinder to keep the snow shovel raised and the ground to a certain degree. distance.

The lifting hydraulic system and the deflection hydraulic system share a hydraulic source. The electromagnetic directional valve is used to quickly extend and retract the piston rod of the lifting hydraulic cylinder, thereby realizing the lifting action of the snow shovel.

## 4. Simulation analysis of the snow removal robot's hydraulic system

### 4.1 Selection of hydraulic system and setting of simulation parameters

The total mass of the selected snow shovel deflection mechanism, lifting mechanism and hydraulic cylinder assembly is 25kg. According to experience, the hydraulic pump model is initially determined as CBN-G316, nominal displacement 25ml/min, rated pressure 3.0MPa, rated speed 2500r min, deflection hydraulic cylinder inner diameter 20mm, rod diameter 12mm, stroke 75mm, lifting hydraulic cylinder inner diameter 20mm, rod diameter 12mm, total stroke 150mm. The hydraulic motor adopts BM2-50, the flow rate is 5~45ml/r, the pressure is adjustable from 5~20MPa, the oil tank volume is 5L, and the internal diameter and rod diameter of the yaw hydraulic cylinder, lifting hydraulic cylinder and the flow rate and pressure of the hydraulic motor are used as input , AMESim simulation software is used to simulate and analyze the pressure, piston rod displacement, hydraulic motor speed and torque of the yaw and lift hydraulic cylinders.

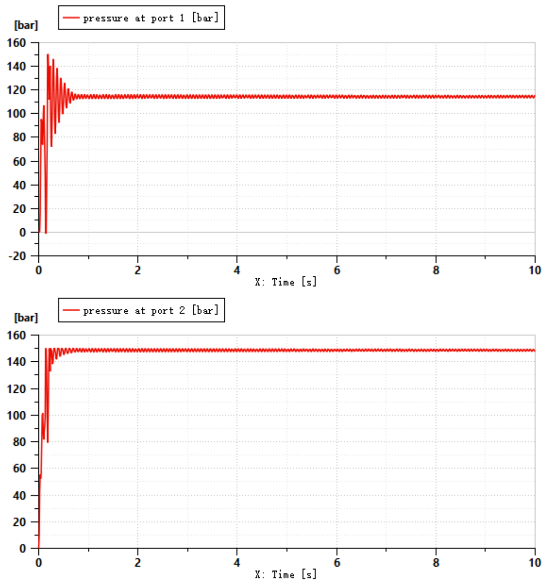



Fig. 6 Pressure curve of yaw hydraulic cylinder 1 port

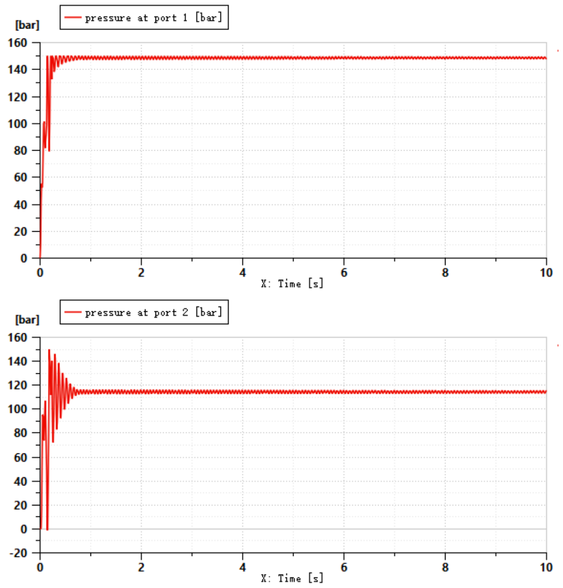



Fig. 7 Pressure curve of the 2-port yaw hydraulic cylinder

As shown in Figure 6 is the pressure curve of the port 1 of the yaw hydraulic cylinder. From the figure, it can be seen that when the hydraulic load input is 25 kg, the pressure P1 of the port 1 of the yaw hydraulic cylinder 1 is 118 bar; the port of the yaw hydraulic cylinder 1 2 The pressure P2 is 150 bar; the pressure difference across the port is:

$$\Delta P = P_2 - P_1 = 32bar \tag{9}$$

Therefore, the piston rod of the yaw hydraulic cylinder 1 moves downward.

As shown in Fig. 7 is the pressure curve diagram of the port 2 of the yaw hydraulic cylinder. It can be seen from the figure that when the hydraulic load input is 25 kg, the pressure P1 of the port 1 of the yaw hydraulic cylinder is 150 bar. The pressure P2 of the port 1 of the yaw hydraulic cylinder 2 is 118 bar; the pressure difference between the two ends of the port is:

$$\Delta P = P_1 - P_2 = 32bar \tag{10}$$

Therefore, the piston rod of the yaw hydraulic cylinder 2 moves upward. Push the snow shovel to the left. Otherwise, push the snow shovel to the right.

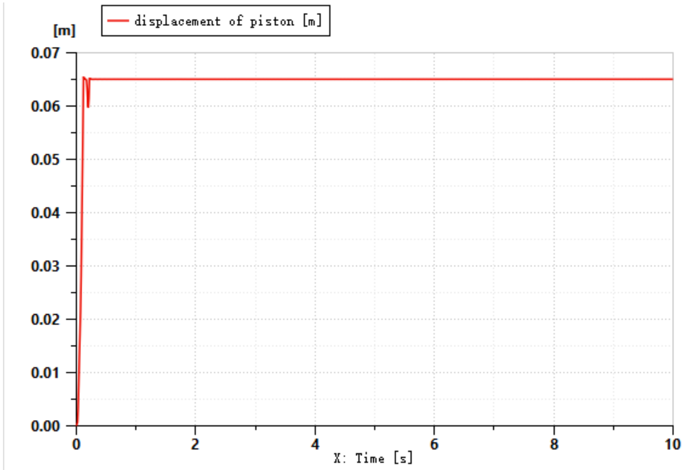



Fig.8 Extension of the piston rod of yaw hydraulic cylinder 2

As shown in Figure 8, the piston rod extension of the yaw hydraulic cylinder 2 can be seen in the figure: the piston rod extension of the 0.1s yaw hydraulic cylinder 2 reaches 0.075m, and the stroke range of the selected hydraulic cylinder Within this, the piston rod of 0.1s hydraulic cylinder can be extended to 0.075m, the response is rapid, and the effective deflection of the deflection hydraulic cylinder can be fully achieved.

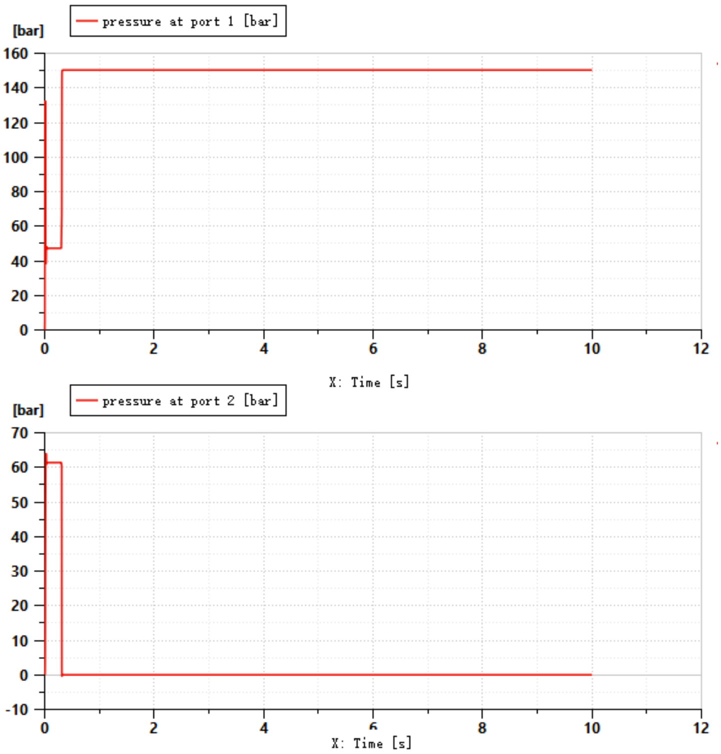



Fig.9 Pressure curve of lifting hydraulic cylinder port

As shown in Figure 9, the pressure curve of the lift cylinder port can be drawn from the figure: the pressure of the lift cylinder port 1 rises from 50bar to 150bar, the pressure at the bottom of the piston rod increases, and the pressure of the lift cylinder port 2 decreases from 60bar At 0 bar, the pressure on the upper part of the piston rod decreases, so the piston rod of the lifting hydraulic cylinder moves upwards, and the rising length is as shown in Figure 10. The elongation of the piston rod of the lifting hydraulic cylinder of 0.2s reaches 0.15m. The rod is completely ejected to achieve the effect of ascent, and it is also within the range of the stroke of the selection hydraulic cylinder, which can realize the lifting of the lifting hydraulic cylinder.

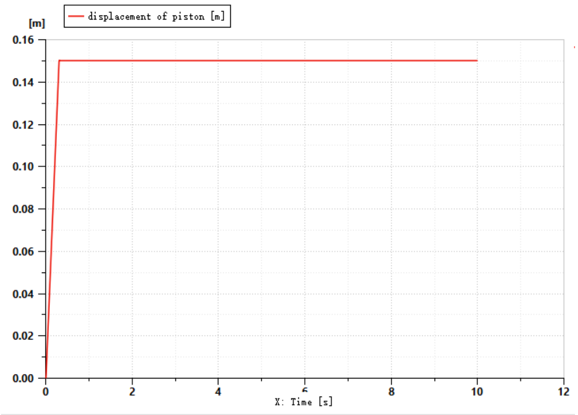



Fig.10 Extension of the piston rod of the lifting hydraulic cylinder

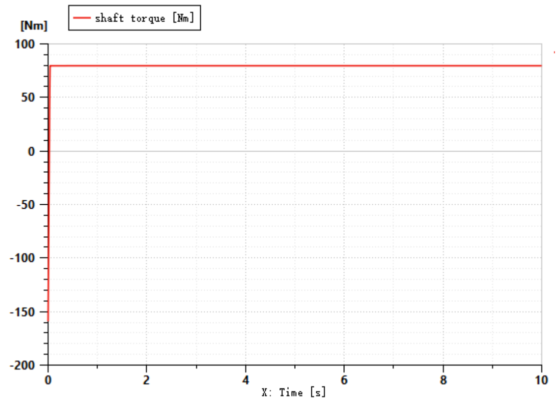



Fig. 11 Hydraulic motor output torque curve

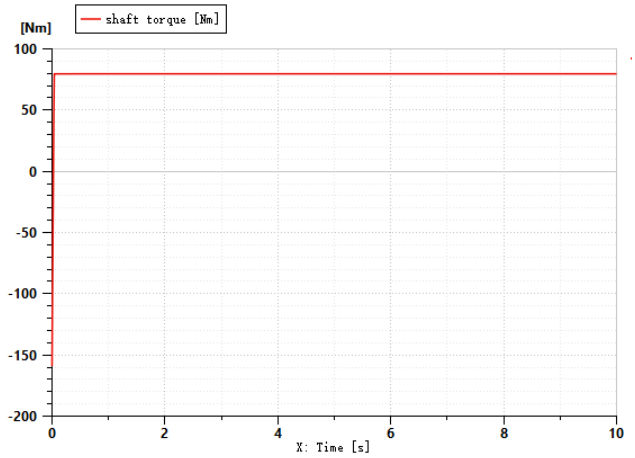



Fig. 12 Hydraulic motor output speed curve

As shown in the output torque curve of the hydraulic motor in Figure 11 and the output speed curve of the hydraulic motor in Figure 12, it can be seen from the figure that when the hydraulic motor is fully open, the output torque is, the speed is 222.818 rev/min, which is exactly the same as the selected hydraulic pressure. The pump (CBN-G316) is matched. The selection of hydraulic pump is: nominal displacement 25ml/min, rated pressure 25MPa, rated speed 2500r/min.

## 5. Conclusion

In this paper, the structure of the snow-plowing robot snow shovel device is designed. The hydraulic system circuit is designed by analyzing the force of the snow-plowing robot snow shovel device. Finally, AMESim simulation software is used to simulate and analyze the snow-plow robot snow shovel hydraulic system. The results show that the hydraulic system exhibits a very high reliability during operation. When subjected to a large external load impact, the hydraulic system can effectively perform overload protection, and the piston rod can still be accurately ejected and retracted. After the load disappears, the hydraulic system can automatically restore the snow shovel device to its original position. The running speed of the actuators in the entire hydraulic system can be adjusted as needed to ensure the stable operation of the snow cleaning robot in different environments. At the same time, the design is intelligent, efficient and simple to operate, and can replace traditional snow sweepers and manual snow removal. The device makes up for the deficiencies of the existing technology to a great extent, and is suitable for various occasions such as highways, airports, urban roads, etc. This efficient work can bring great market value.

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