Energy Recovery Simulation Research of Demolition Robot Rotation Hydraulic System

Peng CHAI*, Yu-wan CEN, Xiao-hua YE, Jian-zhong HUANG and Li-hua WANG

College of Mechanical Engineering, Anhui University of Technology, Ma'anshan, Anhui, China
*Corresponding author

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Abstract. When the robot rotates to brake, the oil circuit of the system will produce greater pressure impact due to the large moment of inertia. High pressure oil overflows through the relief valve, then the overflow back pressure provides negative torque to brake the turntable. The rotational kinetic energy is finally dissipated in the form of heat energy, resulting in the waste of energy and the increase of oil temperature as well as the decline of system performance. Therefore, a scheme of recovery and utilization of rotary kinetic energy is proposed, that is, to recover the kinetic energy of the turntable during the rotary braking and to use the recovered energy as auxiliary energy during the rotary start-up. Virtual.Lab-Motion and AMESim are used to establish the joint simulation model of the electromechanical and hydraulic system of the demolition robot. The simulation results show that the energy recovery efficiency of the scheme can reach over 65%, and the comprehensive energy saving efficiency can reach about 10%.

Introduction

The demolition robot is widely used in all kinds of engineering construction due to its characteristics of high power, multiple functions and intelligence [1]. The demolition robot can realize the demolition, excavation, grasping, handling and other operations by changing the working equipment. In all kinds of working conditions, the rotary motion is frequent and its energy consumption is high. According to the data [2], the energy consumed by the rotary accounts for about 25%~40% of the total energy consumption of the excavator, and the heat generated by the rotary accounts for about 35%~40% of the heat generated by the system. Because the breaking robot adopts load sensitive system, the power adaptability of load sensitive pump can avoid the overflow loss in start-up stage. However, there is still a large amount of energy waste in the rotary braking process. Some scholars have done some research on the energy recovery of rotary system. LIU et al. [3] designed a rotary braking energy recovery program with hydraulic motor and generators as the recovery method and ultracapacitor as the energy storage element, realizing that the energy recovery efficiency can reach over 40% without affecting the rotary driving performance of excavator. However, there are many energy conversion links in this scheme, which reduces the energy recovery efficiency to a certain extent. WEI et al. [4] constructed a hydraulic excavator slewing system based on the secondary regulation technology. The braking energy recovery efficiency of this system can reach 62.4%, which is 24.7% higher than that of an ordinary hydraulic excavator under the same working condition. However, the technology about the secondary components used in this scheme is immature and has not been widely used. LIU et al. [5] proposed a compound recovery method based on motor generator and hydraulic accumulator, which can not only recover energy, but also improve the starting and braking performance of rotary platform. However, the scheme is more complex and costly. FEI et al. [6] provided a rotary braking energy recovery system for tower crane by using pump, motor and accumulator. The recovered energy was used for auxiliary power of cooling system of tower crane. However, the influencing factors of energy recovery rate were not studied. In this paper, a scheme of energy recovery and utilization is designed, in which the braking kinetic energy is recovered by using
the skin type hydraulic accumulator and the output torque of the motor is reduced through driving the auxiliary motor. The reversing of the reversing valve, the opening and closing of the switching valve and the displacement regulation of the auxiliary motor can be controlled according to the recognition of the rotary motion state by the controller, and the function of using the energy recovered during braking as the auxiliary energy can be realized. Virtual.Lab-Motion and AMESim are used to establish the simulation model. Based on the it, the energy recovery efficiency and its influencing factors are analyzed.

The Mechanical Structure of the Demolition Robot and the Design of Energy Recovery and Utilization Rotary System

Introduction to the Structure of the Demolition Robot

The structure of the robot is shown in figure 1.

Figure 1. Structure diagram of the demolition robot.

As can be seen from figure 1, the demolition robot can be divided into rotary device, walking device, mechanical arm working device and chassis. The rotary device consists of a mechanical part and a hydraulic part. The mechanical part includes a slewing drive and a slewing support. The rotary drive consists of a rotary motor and a reducer, which are usually integrated. Since the mechanical arm, core components and counterweight are all arranged on the rotary platform, a large inertia moment will be generated in the rotary process. And the rotary braking contains a considerable amount of recoverable kinetic energy.

Structure Design and Working Principle of the Energy Recovery and Utilization System

The structure and control principle of the new system are shown in figure 2.
It is assumed that the direction of rotation is positive when the oil is fed into the left cavity of the rotary motor. When the turntable starts forward, the proportional valve 9 and the reversing valve 18 and 21 all work in the right position, and the right chamber of the motor exhibits low pressure. When the pilot signal issued the brake command, the proportional valve 9 back to the middle, the reversing valve 21 gets power, the switch valve 15 close, and the reversing valve 18 is still working in the right position. The rotary table still rotates in the positive direction under the action of inertia. The pressure oil in the right chamber no longer flow through the safety valve 14, but through the accumulator 20. Under the back pressure of accumulator, the rotating speed of the turntable decreases from the maximum value to zero value. The rotational kinetic energy is eventually converted into hydraulic energy, which stored in the accumulator. In order to prevent air suction, the oil flows into the motor through the check valve 11 and the right position of reversing valve 18 in the process of braking. Under the action of the accumulator, the auxiliary motor and the electromotor drive the main pump jointly.

**Establishment of the Energy Recovery and Utilization Rotary System Simulation Model**

Figure 3 shows the established joint simulation model of energy recovery and utilization rotary system. The load-sensitive pump control valve set is encapsulated in the model.
Analysis and Calculation of the Energy Recovery Efficiency

"The demolition robot rotates at an angular speed of 9.76r/min under a certain attitude and braking at 7.5s" is selected as the simulation condition to analyze the energy consumption during braking of the original system and the energy recovery rate of the energy recovery system. Figure 4-6 show the angular velocity curve of the turntable, the chamber pressure curve of the rotary motor and the power consumption curve of the safety valve of the original system.

After the angular velocity of the turntable drops to zero for the first time, there is a big fluctuation, and the turntable swings back and forth as can be seen from figure 4.
As can be seen from figure 5, the pressure level of the two chambers of the motor changes during braking, and the pressure of the oil return chamber instantly reaches the opening value of the safety valve. With the swing of the turntable, the pressure of the two cavities gradually attenuates and finally stabilizes.

As can be seen from figure 6, the overflow of the safety valve causes a large amount of energy dissipation on its valve opening. Higher peak power indicates greater hydraulic impact on the system.

The empirical formula method can be used to preliminarily match the parameters of the accumulator, but the error and complexity of this method is large and there is no unique criterion. In this paper, the electromechanical and hydraulic combined simulation model of the rotary system has been established. On this basis, the parameters of the accumulator are preliminarily determined by means of simulation test. By integrating the relief valve overflow flow curve, it can be obtained that the overflow volume is about 0.5L. In order to fully absorb the oil volume during braking, the initial volume of the accumulator can be set to 3L primarily, and then the initial pressure can be selected according to the desired braking effect. Through multiple simulations, the initial pressure is temporarily set at 6MPa.

Figure 7-9 respectively show the turntable angular velocity curve, accumulator pressure and volume curve, and accumulator recovery power curve of the energy recovery rotary system.

As can be seen from figure 7, the angular velocity fluctuation of the demolition robot with the energy recovery system is obviously reduced, and the braking process is more stable.

As can be seen from figure 8, the pressure of the accumulator increases from 60bar to 96bar, and the volume decreases from 3L to 2.15L. Energy recovery and storage are realized.

According to figure 9, the energy recovered by the accumulator reach 6.47kJ.

During the braking process of the rotary device, all the kinetic energy of the turntable is dissipated in the form of heat energy Q.

\[ Q = \frac{1}{2}(J\omega_1^2 - J\omega_2^2). \]  

(1)

Which J is the moment of inertia of the rotary mechanism, which is 22000kg\cdot m^2 under this working condition. \( \omega_1 \) is the angular velocity before braking of the rotary mechanism, which is 9.76 r\cdot min^{-1}. \( \omega_2 \) is the angular velocity of rotation mechanism after braking, which is 0 r\cdot min^{-1}.

\[ \eta = \frac{E}{Q} \times 100\%. \]  

(2)
Which η is the energy recovery efficiency, E is the energy recovered by accumulator.
Then, getting the result as follows.
Q= 11.48kJ, E= 6.47kJ, η=56.4%.

Analysis of the Influencing Factors of Energy Recovery Efficiency

Influence of the Different Initial Pressure of Accumulator

Using the control variable method, the initial volume of the accumulator is set to 3L, and the initial pressure is set to 5MPa, 6MPa, 7MPa, 8MPa, 15MPa and 30MPa, respectively. The influence of the initial pressure of the accumulator on the energy recovery rate and the angular velocity of the turntable are shown in Figure 10-12.

As can be seen from figure 10, with the increase of the initial pressure of the accumulator, the energy recovered increases, but the increase rate slow down. In addition, the peak value of the recovery power increases with the increase of the initial pressure of the accumulator, but the recovery time will be shorter.

It can be seen more intuitively from figure 11 that with the increase of initial pressure, the energy recovery rate also increases and the increase rate gradually decreases. When the initial pressure is too high, the energy recovery rate increases more slowly.

As can be seen from figure 12, the greater the initial pressure is, the more obvious the swing phenomenon of the turntable is during braking.

Based on the above analysis, the higher energy recovery rate and gentler braking effect can be achieved at the initial pressure within the range of 8~15MPa.

Influence of the Different Initial Volume of Accumulators

Using the control variable method, the initial pressure of the accumulator is set to 12MPa, and the initial volume is set to 1L, 2L, 3L, 5L, 10L and 20L, respectively. The influence of the initial volume of the accumulator on the energy recovery rate and the angular velocity of the turntable is shown in Figure13-15.
As can be seen from figure 13, with the increase of the initial volume of the accumulator, the recovered energy decreases, but the decrease rate slow down.

It can be seen more intuitively from figure 14 that with the increase of the initial volume, the energy recovery rate gradually decreases, and the decrease rate gradually slow down. The energy recovery rate displayed in the figure is within the range of 65.33%~68.92%. Since 12MPa is the initial pressure match with a high energy recovery rate, the energy recovery rate is high and the change range is small.

As can be seen from figure 15, the smaller the initial volume is, the more obvious the shaking of the angular velocity of the turntable is.

According to the above analysis, increasing the initial pressure or decreasing the initial volume can improve the energy recovery rate of the accumulator, but the swing of the turntable increased. Therefore, it is a better matching result to choose a parameter combination that takes both performance into consideration. The paper finally set the initial pressure as 10MPa and the initial volume as 3L.

**The Releasing of the Recycled Energy**

The recovery and utilization of rotary braking energy are analyzed by taking a positive and negative turning period of the turntable as the simulation condition. Figure 16-18 show the angular velocity curve of the turntable, the pressure and volume curve of the accumulator, and the torque coupling curve.

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[Figure 13. Comparison curves of accumulator recovery power and energy under different initial volumes.]

[Figure 14. Energy recovery rate at different initial volumes.]

[Figure 15. Angular velocity comparison curves of the turntable under different initial volumes.]

[Figure 16. Angular velocity curve of the turntable.]

[Figure 17. Accumulator pressure and volume curves.]
As can be seen from figure 16, the energy recovery and utilization system does not affect the original rotary angular velocity characteristics of the demolition robot. It can be seen from figure 17 that the accumulator effectively recovers energy during braking and releases energy during start-up. Figure 18 shows that when the turntable is started, the accumulator drives the auxiliary motor, which is coupled with the motor in torque. Thereby, the output torque of the motor is reduced.

Summary

In order to solve the problem of the waste of rotary kinetic energy in the rotary braking of demolition robot, a scheme of energy recovery and utilization is designed. Through simulation research, it can be concluded that:

1. The energy recovery scheme is feasible in energy saving. The simulation results show that the energy recovery efficiency of the scheme can reach over 65%, and the comprehensive energy saving efficiency can reach about 10%.

2. With the increase of initial pressure, the energy recovery rate increases, but the increase rate decreases gradually. With the increase of the initial volume, the energy recovery rate decreases, and the reduction amplitude decreases gradually.

3. The parameter matching and optimization of accumulator and motor in energy recovery unit can be further studied.

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