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Energy-Saving Control of a Novel Hydraulic Drive System for Field Walking Robot

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Abstract. To improve the efficiency of the hydraulic drive system in field walking robot, this paper proposed a novel hydraulic system based on two-stage pressure source. Based on the analysis of low efficiency of robot single-stage hydraulic system, the paper firstly introduces the concept and design of two-stage pressure source drive system. Then, the new hydraulic system energy-saving control is planned according to the characteristics of walking robot. The feasibility of the new hydraulic system is proved by the simulation of the walking robot squatting. Finally, the efficiencies of two types hydraulic system are calculated, indicating that the novel hydraulic system can increase the efficiency by 41.5%, which can contribute to enhance knowledge about hydraulic drive system for field walking robot.

1. Introduction

With the rapid development and integration of control technology, perception technology and new material technology, the walking robots have realized the complex functions of entertainment services, human-computer interaction and environmental detection [1-2]. However, most walking robots are driven by motor, powered by high-capacity lithium batteries or external cables, causing low power density. What's more, small load capacity and low speed limit the working range of walking robot. For example, the robots used in non-structural battlefields need to be equipped with large load capacity and high speed to carry weapons and equipment for soldiers to carry supplies for the battlefield. Therefore, how to build a drive system with high power density characteristics and high energy efficiency is the key problem to develop the field walking robot [3-5].

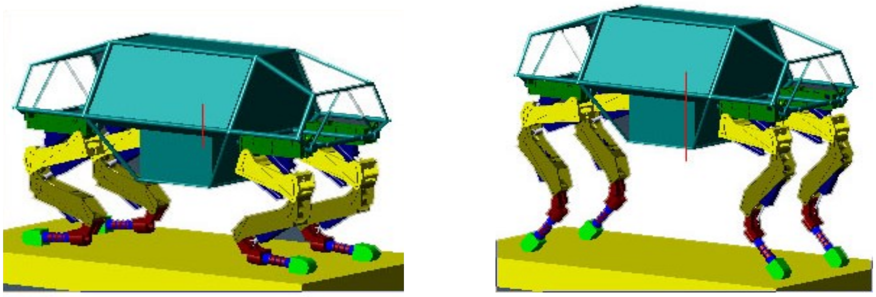
To further improve load capacity, researchers have begun experimenting with hydraulic systems that drive field walking robots [6]. One of the most excellent robots is the "Big Dog" developed by Boston dynamics in the United States, which can load up to 50kg [7]. The company's latest development, LS3, is capable of carrying 181kg of weight [8]. However, the drive efficiency of the hydraulic power system applied to the robot is relatively low, which is mainly caused by the difference output in displacement and force of the field walking robot in the same instantaneous actuator. In order to ensure the robot to walk normally, pump source output power must always meet for the maximum load power requirements instantly, reducing the hydraulic drive system efficiency [9-10].

How to improve the efficiency of the hydraulic drive system of field walking robot, so that the energy can be fully utilized to improve the load capacity, motion ability and endurance of the walking robot, so an efficient hydraulic drive system based on two-stage pressure source is proposed in this paper. The paper firstly introduces the design of the two-stage pressure source drive system. Then, its energy-saving control method is planned according to the characteristics of walking robot. Finally, the energy saving effect of two-stage pressure source drive system is simulated based on the example of field walking robot squatting.

2. Design of Two-Stage Pressure Hydraulic Drive System

At present, most field robots hydraulic systems adopt single-stage driving mode. The hydraulic actuator is powered by the hydraulic pump which driven a gasoline engine or motor. In order to satisfy the robot to perform various movements, it is necessary to design the drive the hydraulic system according to the maximum load.

As shown in figure 1, the robot is transformed from squatting to standing. Figure 2 shows the load curves of three joint of hydraulic cylinders during the squatting motion. As can be seen from figure 2, when the robot stands up, the maximum load appears in the initial standing moment of the ankle joint, with a load of nearly 4000N. However, with the increase of joint angle, the load capacity of the robot decreased rapidly, and the robot reached the minimum when it stands up completely, and the load was only 1200N. When the robot squats down, the load on the ankle is reversed.



(a) Moving state of squatting (b) Moving state of standing

Figure 1. Squatting and standing of walking robot in the field

In this kind of drive mode, the robot performs lower power motion, due to the high pressure in system, it will inevitably result in a lot of pressure drop loss and energy waste. At the same time, other joints are less loaded, which also causes stress loss. The energy waste will lead to the system heat up, the power of the cooling system increases, and the volume and weight of the cooling system also increases.

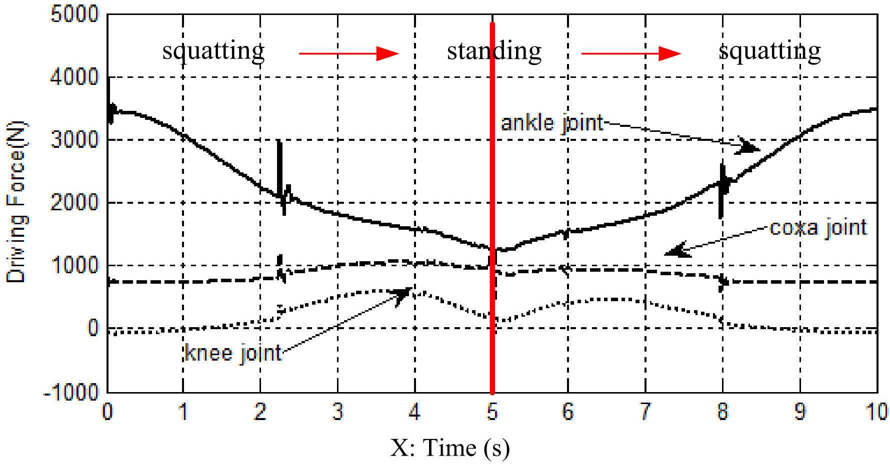


Figure 2. The load curves of three different moving joints

To ensure that the robot can accomplish all the required tasks, and improve the efficiency of the power supply system as much as possible. This paper presents an efficient two-stage hydraulic drive system. Use the accumulator to construct a high-power unit with instantaneous high pressure, match a low pressure variable pump system to realize the two-stage driver, as shown in figure 3.

The system has two pressure sources, one is the low-pressure source, the other is the high-pressure source. The low pressure source is directly available to all actuators, and the high pressure pump is used to charge accumulator. When the control system detects that the accumulator pressure is added to the predetermined pressure value, the controllable clutch causes the high pressure pump to disengage from the gasoline engine. When the high-pressure accumulator releases energy and is lower than the preset pressure value, the control system sends instructions to connect the high-pressure pump with the gasoline engine to charge the accumulator.

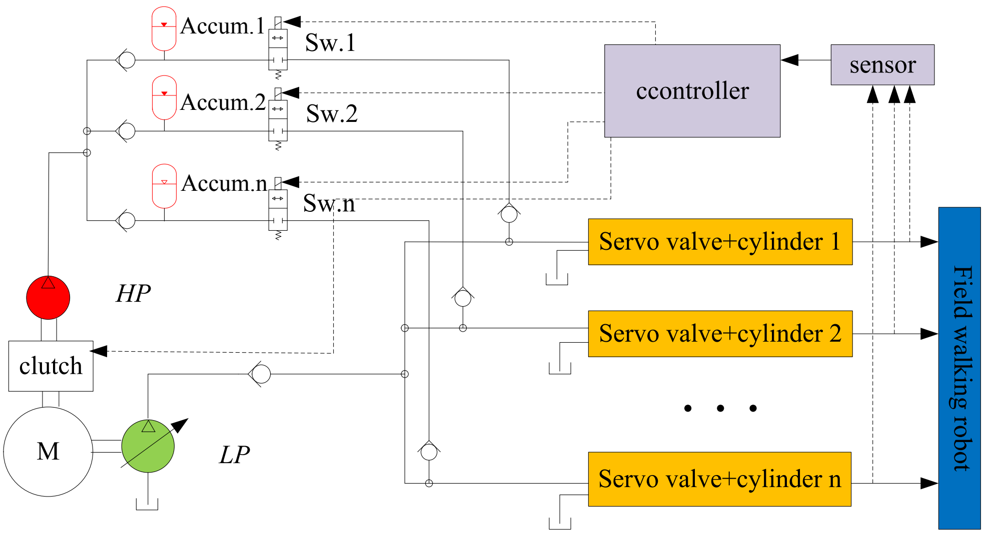


Figure 3. Schematic diagram of two-stage system

The walking robot actuator is composed of a servo valve and a straight line hydraulic cylinder. Each actuator is supplied by a low pressure pump source and a small auxiliary high pressure accumulator. According to the change of the carrying capacity, when the robot walks, the actuator is supplied by the low pressure variable pump source and the high frequency switch valve is closed. When the instantaneous large driving force is needed, the low pressure pump source cannot provide the required pressure, the high frequency switch valve is in the opening state, the actuator is supplied by the high pressure source.

3. Control Strategy

According to the characteristics of walking robot, the control strategy of two-stage pressure system is proposed, as shown in figure 4.

When load $F_{load} < \tau_1 F_{max}$, the current load capacity is small, and the low-pressure system can be used $p_{in} = p_{\mathrm{L}}$. When load $F_{load} \geq \tau_1 F_{max}$, judge the valve port size. If $u \geq \tau_2 u_{max}$, it indicates that the current system is insufficient to supply, and switch to the high-pressure system $p_{in} = p_{\mathrm{H}}$. When $u < \tau_2 u_{max}$, the system supply capacity still meets the requirements, so the pressure system remains constant $p_{in} = p_{\mathrm{L}}$. Where, F_{max} is the maximum load capacity of the low pressure system, u_{max} is the maximum open control of the valve, τ_1 and τ_2 is the safe value.

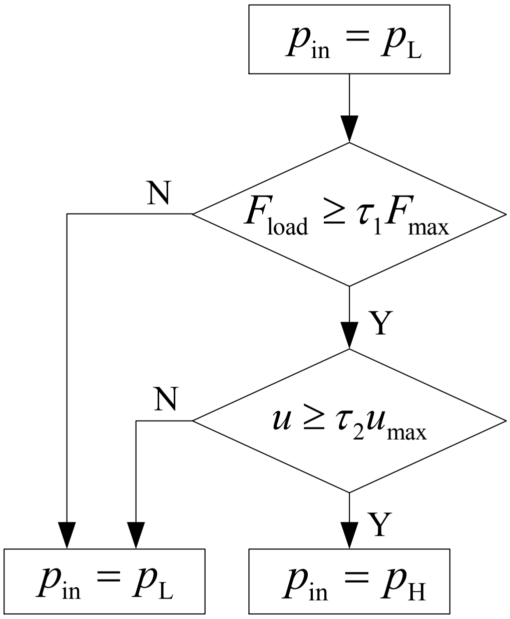


Figure 4. Control strategy of two-stage pressure system

4. Simulation Analysis

In this section, the efficiency of two-stage hydraulic system in the squat gait of robot is simulated based on the AMSEim. As shown in figure 2, the ankle joint motion is selected for the analysis, as the load of the ankle joint is more intense than the other joint loads. The load and the displacement of hydraulic cylinder in robot squatting of ankle are inputs of single-stage system and double-stage system respectively. The simulation parameters are shown in table 1.

Table 1. Key parameters in the simulation

Parameter	Value
The inner diameter of hydraulic cylinder	0.023 m
The diameter of cylinder rod	0.012 m
The natural frequency of the servo valve	100 Hz
The natural frequency of the switch valve	200 Hz
The pressure of the low-pressure	7 MPa
The pressure of the high-pressure	21 MPa

Based on the simulation, the energy acquired energy, single-stage pressure system consumed energy and two levels of power system consumed energy all can be obtained, As shown in figure 5, the bottom green curve (the chain line) is actual needs of energy, the middle blue curve (the dotted line) describes two-stage pressure system consuming the energy, the above red curve (the solid line) is the consumed energy in a single-stage system.

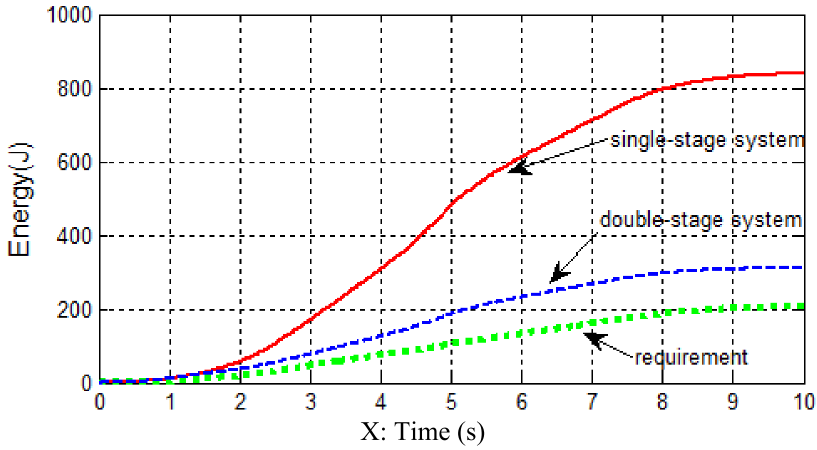


Figure 5. The consuming energy curves in the different hydraulic system

It can be seen from figure 5 that the robot can complete a squat and stand up in 10 seconds, and the total energy of the ankle joint is 205.69 J. The total energy provided by the single-stage pressure system is 837.49 J. The total energy provided by the two-stage pressure system is 311.04 J. According to the concept that the efficiency ratio is useful power to total power, the efficiency of the single-stage pressure system is $\eta_1 = 24.6\%$, while the two-stage energy efficiency is $\eta_2 = 66.1\%$, which means the novel hydraulic system can increase the efficiency by 41.5%.

5. Conclusion

In this paper, an efficient hydraulic drive system based on two-stage pressure source was proposed. The structure of two-stage pressure source drive system was designed, and the reason of the low efficiency in traditional hydraulic system was researched. According to the characteristics of field walking robot, its energy-saving control method is planned. Based the simulation of the walking robot squatting, the feasibility of the new hydraulic system was proved and the efficiencies of two types hydraulic system were calculated, which can contribute to enhance knowledge about hydraulic drive system for field walking robot.

6. Acknowledgments

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