Frontiers in Computing and Intelligent Systems
ISSN: 2832-6024 | Vol. 11, No. 2, 2025

Modeling and Simulation Research on the Hydraulic System of the Blade of an Unmanned Bulldozer

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Abstract: In response to the operational characteristics of unmanned bulldozers, a model of the hydraulic system and physical mechanism of the bulldozer blade was constructed using AMESim software. This paper discusses the modeling process, sets the main parameters of the model, and simulates the dynamic behavior of the hydraulic system and the two-dimensional motion of the mechanism during the processes of digging, pushing, unloading, and resetting of the unmanned bulldozer blade. The simulation curves of pressure, flow rate, and displacement for the lifting and tilting hydraulic cylinders of the blade were obtained. A detailed analysis and comparison of the simulation results were conducted, verifying the accuracy of the model. The study demonstrates that the model improves the operability of the unmanned bulldozer, enabling smoother operation. Additionally, the correctness of the simulation model was validated, which is significant for achieving trajectory planning of the blade.

Keywords: Unmanned Bulldozer; Hydraulic System; AMESim; Motion Simulation.

1. Introduction

Bulldozers are primarily used in large-scale earthwork projects for tasks such as pushing, leveling, and flattening the ground [1]. The blade and its hydraulic system are the most critical components of a bulldozer during operation. In many cases, bulldozers operate in harsh environments, such as on piles of soil, slopes, and trenches, where the external load on the blade varies significantly and frequently, and the hydraulic cylinder oil pressure may become unbalanced [2]. This requires continuous adjustments by the operator, potentially leading to reduced efficiency and compromised ground leveling quality [3]. Moreover, precise operation becomes increasingly challenging for the operator, and ensuring their safety is difficult. Therefore, intelligent unmanned bulldozers represent an important future development direction, meeting the market demand for intelligent bulldozers and offering broad prospects and practical application value [4, 5].

With the rapid advancement of computer technology and virtual prototyping, computer simulation has been widely applied in the field of design and analysis [6]. Simulation analysis of the hydraulic system of a bulldozer blade not only aids in structural improvements but also optimizes control methods, facilitating the development of intelligent and unmanned bulldozers [7].

This paper establishes a simulation model of the unmanned bulldozer blade and its hydraulic system in AMESim based on the actual blade structure and hydraulic system. The model simulates the four operational processes of digging, pushing, unloading, and resetting by transmitting control signals to regulate the pressure, flow rate, and displacement of the hydraulic cylinders. The simulation results are analyzed both qualitatively and quantitatively.

2. Structure of the Unmanned Bulldozer Blade

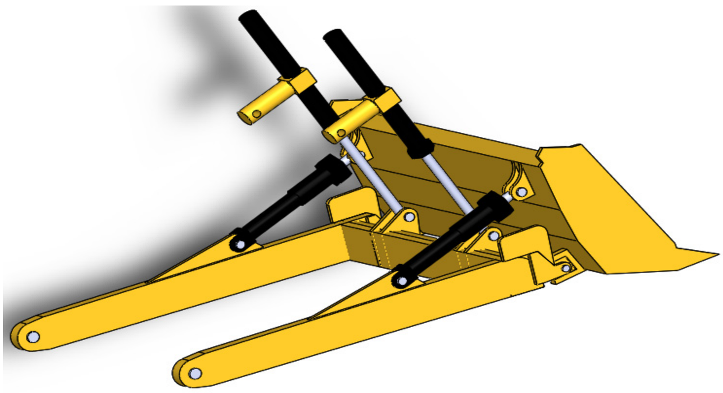


Figure 1. Structure of the Blade

The structure of the unmanned bulldozer blade is shown in Figure 1. The blade primarily consists of the blade plate, push frame, two lifting hydraulic cylinders, and two tilting hydraulic cylinders. All components of the blade are connected to the hydraulic cylinders via pin joints [8]. The blade plate is the structure that directly interacts with the soil during operation. The push frame, which is U-shaped, is mounted on the back of the blade plate. One end of the push frame beam is hinged to the blade plate, and two tilting hydraulic cylinders are connected between the blade plate and the push frame, allowing the blade to tilt around the hinge. The other end of the push frame beam is connected to the crawler wheels on both sides of the bulldozer body. Additionally, two lifting hydraulic cylinders are connected to the top of the push frame, with the other end fixed to the body, enabling the push frame to lift the blade around the hinge.

3. Establishment of the Simulation Model

Since the lifting hydraulic cylinders of the unmanned bulldozer blade are symmetrically distributed on both sides of the blade and their stroke changes are consistent, the two lifting hydraulic cylinders can be simplified into a single cylinder. Similarly, the two tilting hydraulic cylinders can also be simplified into one. Based on this, a simulation model of the unmanned bulldozer blade and its hydraulic system was established in AMESim for analysis. The simulation model is shown in Figure 2.

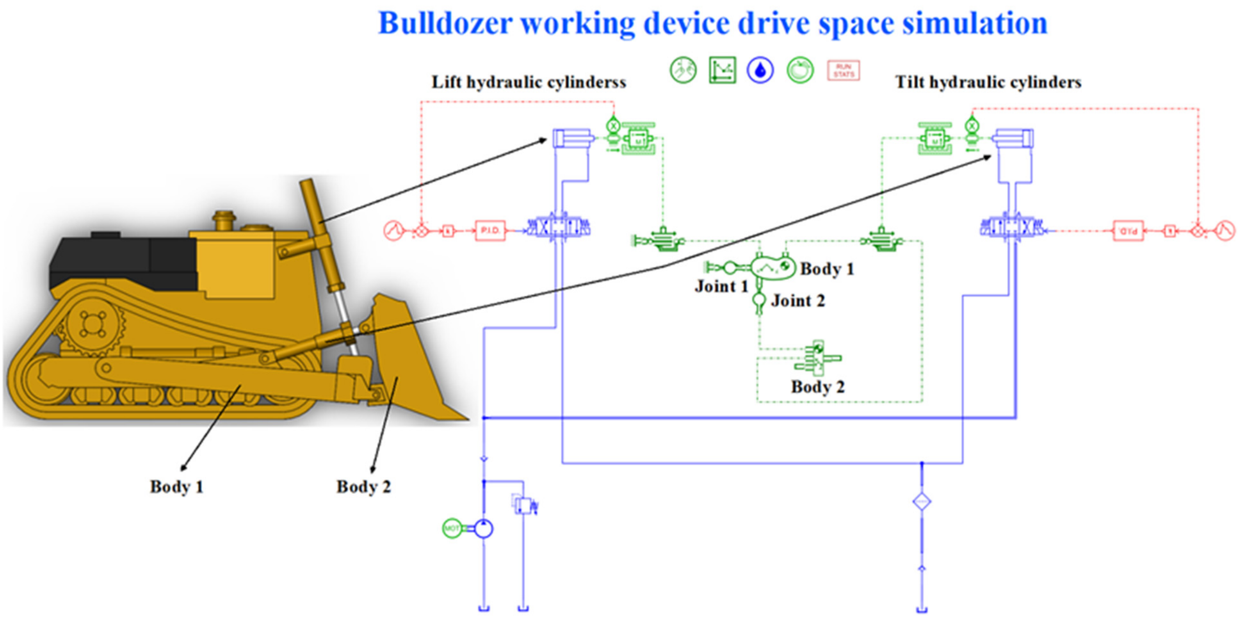


Figure 2. Simulation Model of the Unmanned Bulldozer Blade and Hydraulic System

The hydraulic system of the blade uses two three-position four-way solenoid valves to control the lifting and tilting of the hydraulic cylinders. The directional control signal is directly transmitted to the solenoid valve by a signal generator, and the feedback system directly compares the displacement sensor feedback with the input signal. The hydraulic system's power source is provided by a constant-power hydraulic pump, and excess oil is returned to the tank via a relief valve [9].

In the physical model, the push frame of the unmanned bulldozer is defined as Body1, and the blade plate is defined as Body2. Joint1 and Joint2 are the hinge points between the push frame and the body and between the blade plate and the push frame, respectively. Based on the actual dimensions of the unmanned bulldozer, the center of gravity coordinates and mass of the two bodies, the coordinates of the hinge points, and the simulation parameters of the hydraulic cylinders (such as cylinder diameter, piston rod diameter, stroke, and oil pressure) were input [10]. In AMESim, the lifting hydraulic cylinder has a cylinder diameter of 130 mm, a rod diameter of 80 mm, and a stroke of 1100 mm. The tilting hydraulic cylinder has a cylinder diameter of 100 mm, a rod diameter of 70 mm, and a stroke of 500 mm. The push frame (Body1) has its origin at the absolute coordinate system's origin, with a center of gravity at (2, 0). The hinge point with the blade plate (Body2) is at (4, 0), the hinge point with the tilting hydraulic cylinder is at (3.1, 0), and the hinge point with the lifting hydraulic cylinder is at (3.9, 0). The mass of the push frame is 100 kg. The blade plate (Body2) has its origin at (4, 0) in the absolute coordinate system, with the hinge point to the push frame (Body1) at the origin of the relative coordinate system. The center of gravity is at (0.3, 0.3), the hinge point with the tilting hydraulic cylinder is at (0, 0.8), and the coordinates of the blade plate's end teeth are (1, -0.5). The mass of the blade plate is 50 kg, and the hinge point of the tilting hydraulic cylinder with the body is at (3, 2) in the relative coordinate system.

Other simulation parameters of the hydraulic system, such as viscous friction coefficient, leakage coefficient, damping coefficient, elastic stiffness, and deformation, were set using the software's recommended empirical values, as shown in Table 1.

Table 1. Other Hydraulic System Parameters

Name	Parameter
Viscous Friction	0 N/(m/s)
Leakage Coefficient	0 L/min/bar
Damping Coefficient	10000 N/(m/s)
Hydraulic Cylinder Stiffness	10000 N/mm
Deformation	0.001 mm

After setting the above parameters, the two-dimensional model of the unmanned bulldozer blade was obtained in

AMESim's 2D mechanical library, as shown in Figure 3.

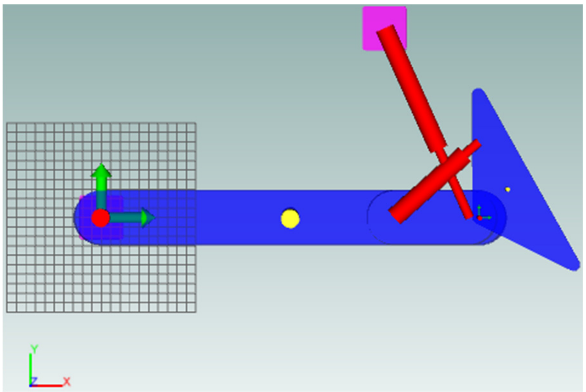
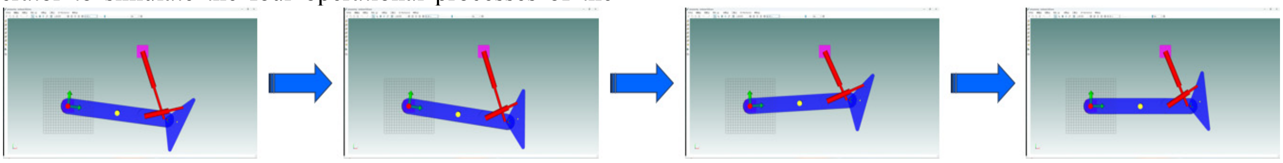


Figure 3. Schematic Diagram of the 2D Model of the Unmanned Bulldozer Blade

4. Simulation and Result Analysis

In AMESim, four-step signals were input into the signal generator to simulate the four operational processes of the unmanned bulldozer blade: digging, pushing, unloading, and resetting. The schematic diagram of the two-dimensional operational process is shown in Figure 4.



spade **bulldozing** **soil dumping** **reset**

Figure 4. Schematic Diagram of the Blade's Operational Process

4.1. Displacement Analysis of Hydraulic Cylinders

As shown in Figure 5, the red and blue curves represent the displacement changes of the lifting and tilting hydraulic cylinders, respectively. Based on Figure 5, the working cycle of the hydraulic system is as follows:

Lifting Hydraulic Cylinder: The red curve shows that from 0 to 10 seconds, the lifting hydraulic cylinder extends from 0 m to its maximum displacement of 1.1 m, lowering the blade for digging. From 10 to 30 seconds, the cylinder's displacement remains unchanged, maintaining the blade's position for pushing. From 30 to 40 seconds, the cylinder retracts to 0.4 m, raising the blade for unloading. From 40 to 50 seconds, the blade resets to the horizontal position, with the cylinder's displacement at 0.6 m.

Tilting Hydraulic Cylinder: The blue curve shows that from 0 to 10 seconds, the tilting hydraulic cylinder extends from 0 m to its maximum displacement of 0.5 m, tilting the blade to a 60° angle for digging. From 10 to 20 seconds, the cylinder retracts, keeping the blade vertical for pushing. From 20 to 30 seconds, the cylinder's displacement remains unchanged during pushing. From 30 to 40 seconds, the cylinder extends to 0.5 m, tilting the blade for unloading. From 40 to 50 seconds, the cylinder retracts to its initial position, with a displacement of 0.3 m.

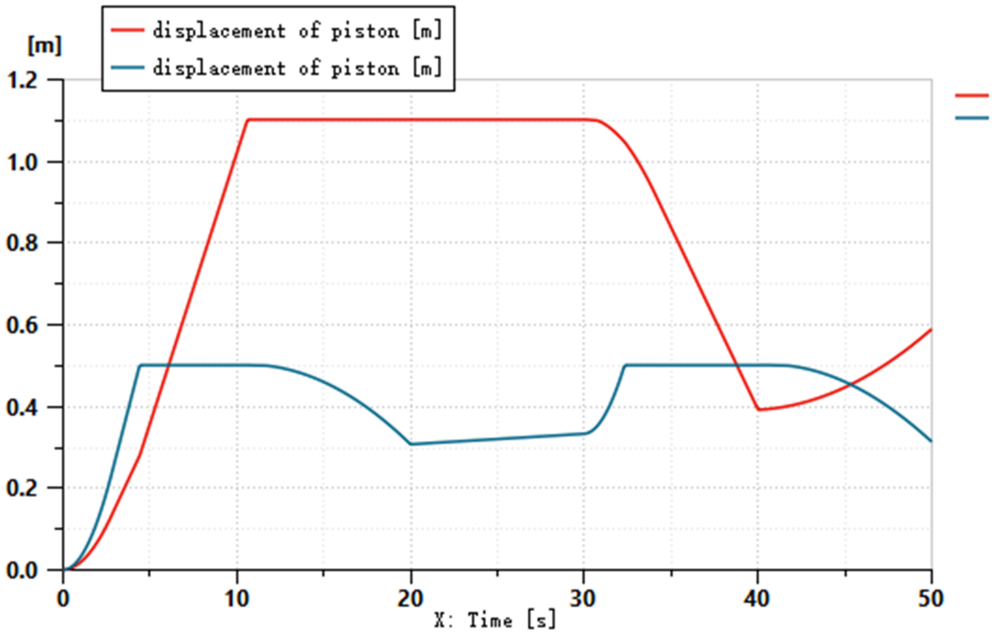


Figure 5. Displacement Curves of the Hydraulic Cylinders

4.2. Pressure Analysis of Hydraulic Cylinder Chambers

As shown in Figure 6, the red and blue curves represent the pressure changes in the working chambers (rodless side) of the lifting and tilting hydraulic cylinders, respectively. From 0 to 10 seconds, as the blade lowers and tilts, both cylinders experience pressure fluctuations within the first 5 seconds. The lifting cylinder stabilizes its pressure from 5 to 10 seconds, reaching a maximum of 150 bar at 10 seconds, while the tilting cylinder reaches its maximum pressure of 150 bar at 5 seconds. From 10 to 20 seconds, as the blade remains stationery and tilts upward, the lifting cylinder's pressure remains unchanged, while the tilting cylinder's pressure drops to 70 bar and stabilizes. From 20 to 30 seconds, the lifting cylinder's pressure remains unchanged, and the tilting cylinder's pressure drops to 20 bar. From 30 to 40 seconds, as the blade rises and tilts downward, the lifting cylinder's pressure drops to 80 bar and stabilizes, while the tilting cylinder's pressure rises to a maximum of 150 bar for unloading. From 40 to 50 seconds, during resetting, the pressures in the lifting and tilting cylinders drop to 70 bar and 30 bar, respectively, and stabilize.

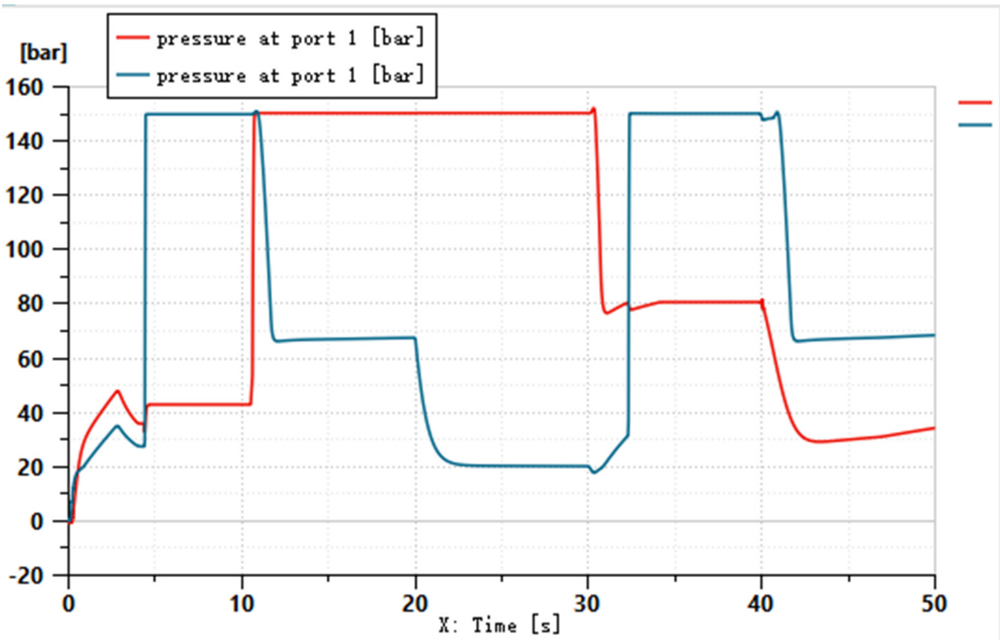


Figure 6. Pressure Curves of the Hydraulic Cylinder Chambers

4.3. Flow Rate Analysis of Hydraulic Cylinder Chambers

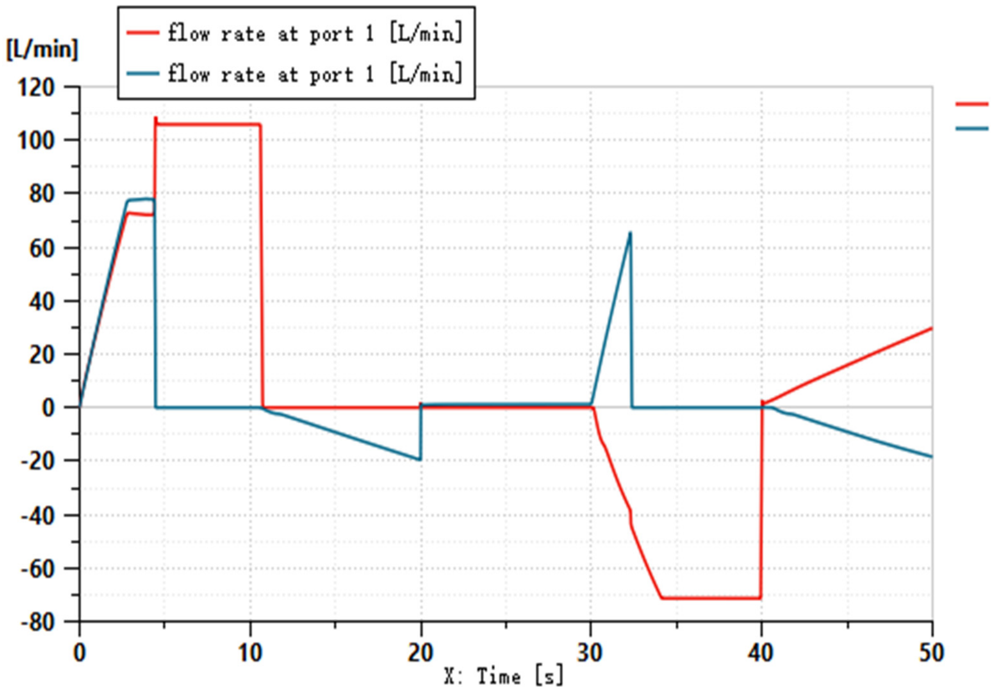


Figure 7. Flow Rate Curves of the Hydraulic Cylinder Chambers

As shown in Figure 7, the red and blue curves represent the flow rate changes in the working chambers of the lifting and tilting hydraulic cylinders, respectively. From 0 to 3 seconds, the flow rates in both cylinders rise to 72 L/min and 79 L/min, respectively, and remain stable from 3 to 5 seconds. From 5 to 10 seconds, the lifting cylinder's flow rate rises to a maximum of 110 L/min and stabilizes, while the tilting cylinder's flow rate drops to 0 L/min. From 10 to 20 seconds, the lifting cylinder's flow rate drops sharply to 0 L/min and remains unchanged, while the tilting cylinder's flow rate gradually drops to -20 L/min. From 20 to 30 seconds, both cylinders' flow rates remain at 0 L/min. From 30 to 40 seconds, the lifting cylinder's flow rate rises to 65 L/min before dropping sharply to 0 L/min, while the tilting cylinder's flow rate drops to -70 L/min and remains unchanged. From 40 to 50 seconds, the lifting and tilting cylinders' flow rates gradually rise to 30 L/min and drop to -20 L/min, respectively, resetting the blade's position.

5. Summary

This paper conducted a simulation analysis of the unmanned bulldozer blade and its hydraulic system using AMESim, focusing on the displacement, pressure, and flow rate changes of the hydraulic cylinders during the processes of digging, pushing, unloading, and resetting. The simulation results demonstrate that the model accurately simulates the changes in the hydraulic system during the blade's operation.

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