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AMESim을 이용한 휠로더 유압시스템의 모델링 및 시뮬레이션에 관한 연구
A Study on Modeling and Simulation of Hydraulic System for a Wheel Loader using AMESim

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Key Words : AMESim(아메심), Hydraulic system (유압시스템), Load-sensing (부하감지), Simulation (시뮬레이션), Wheel loader (휠로더)

Abstract: 본 논문은 유압해석 상용툴인 AMESim을 이용하여 로드센싱형 휠로더 유압 시스템을 모델링 하였다. 휠로더 유압장치의 주요 구성요소인 펌프, 메인 컨트롤밸브, 압력 보상기, 리모트 컨트롤밸브 및 작업 장치를 모델링 하였으며 실제 차량의 제원을 적용하여 시뮬레이션을 수행하였다. 시뮬레이션 결과와 실차 데이터를 비교 검토하여 시뮬레이션 결과와 실차 데이터가 유사함을 알 수 있었다.

1. Introduction

Wheel loader has obtained popularity in various working fields, especially in urban engineering projects and earthmoving works. Consequently, it has been received much attention by many researchers in order to achieve great gains in efficiency, performance, safety and operator comfort1~2). Moreover, an operator of such a vehicle needs a lot of training time and experiences until he can handle a vehicle safely and skillfully. In order to reduce these requirements for the operator as well as to protect from the hazardous working environment, a vehicle should be made as more autonomous way3). This work focuses on as a first step in this direction, a wheel loader hydraulic circuit modeling and simulation program to evaluate loading and unloading task.

The direct field test on the capability of components and controllers of a vehicle requires a lot of time, risk and resources. In order to reduce these, simulation is necessary before the field test4).

This contribution presents AMESim based hydraulic modeling and simulation program for a wheel loader. A wheel loader consists of variable displacement tandem axis piston pump which is load sensing control type along with maximum pressure regulator, and is operated by signals from joystick that control pilot pressure to spools of the main control valve(MCV).

2. Wheel Loader Sub-systems

Wheel loaders can be broken down into four sub-systems: power-train, brakes, steering and hydraulic system for actuators as illustrated in Fig. 1.

The power-train consists of a power source which is typically a diesel engine. Power is transmitted to a mechanical transmission via a torque converter which then connects to differentials, drives and finally tires. Several engine power take-offs provide power via pumps to run the steering hydraulic system, the brake system, and the hydraulic actuation system. The hydraulic actuation system contains the ground

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engaging tools that provide the force and motion to engage the pile that needs to be processed. This article concerns with the modeling and simulation of hydraulic system. The steering system is out of this paper scope. Figure 2 shows the structure of the simulation model5).

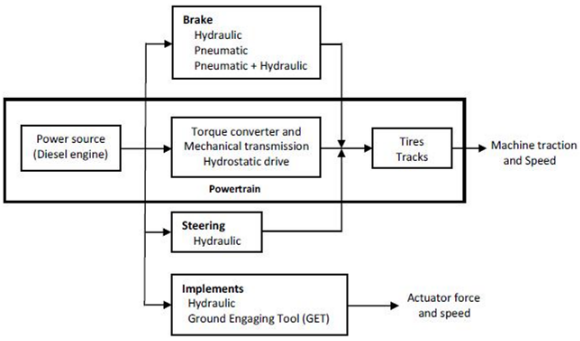

Fig. 1 Block diagram of wheel loader sub-systems

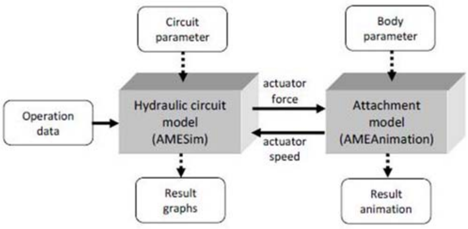

Fig. 2 Structure of the simulation model

3. Modeling of Hydraulic System using AMESim

In order to develop the simulation model, at first the main components of a wheel loader hydraulic circuit such as main pump, MCV, joystick, compensator and attachment are modeled using AMESim, a leading commercial simulation software in the field of hydraulic system6~7). These components modeling are based on typical 23-26 ton hydraulic wheel loader.

3.1 Main pump modeling

The main pump modeled in this paper is variable displacement dual tandem axis piston pumps having pump displacement 100cc/rev and 51cc/rev respectively with load-sensing controller and maximum pressure regulator. Figure 3 illustrates cross-section of a typical variable displacement load-sensing pump.

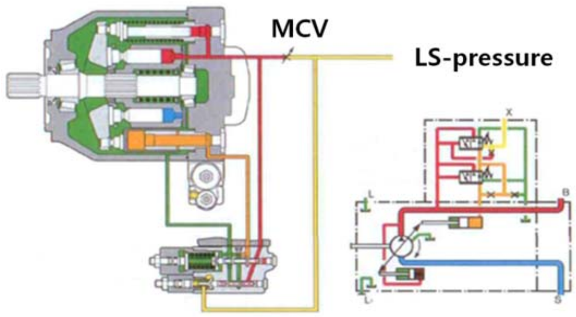

Fig. 3 Cross-section of a typical variable Displacement load-sensing pump

A load-sensing pump is actuated in dependence on the highest load pressure and only produces the flow demanded by the actuators that makes it energy efficient. Figure 4 shows the AMESim model of one section of the main pump.

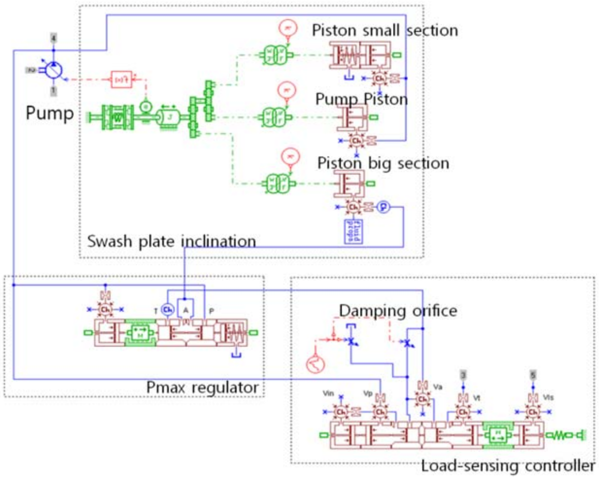

Fig. 4 AMESim model of one section of the main pump

The pump swept volume is a function of the inclination of the swash plate. The swash plate angle is governed by the resulting torque given by the piston small section, pump pistons and the piston big section, controlled by the flow rate given by the load-sensing controller together with maximum pressure regulator. The main dual tandem pump is formed by coupling two pump sections with single motor having shaft speed

2300rev/min.

3.2 MCV modeling

The MCV consists of various valves for boom, bucket and auxiliaries. Only the valves for boom and bucket are modeled in this paper. These valves are 8 ports 3 position types including bypass line as shown in Fig. 5.

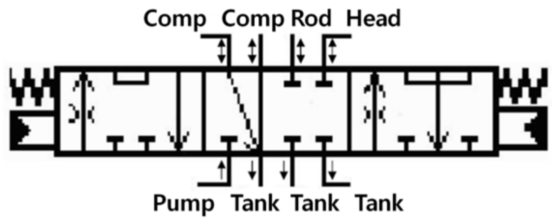

Fig. 5 Hydraulic circuit model of boom and bucket valves

When pilot pressure acts on one side of a valve selectively, spool is moved in accordance with the pressure. Then the flow areas with respect to spool displacement show non-linear relation that illustrate in Figs. 6 and 7.

In course of modeling of MCV valves, the factors considered are the stroke of spool, the mass of spool, the flow area with respect to spool displacement, the diameter of spool, and the end spring stiffness. The model of valves comes from mechanical and hydraulic component design module libraries of AMESim. Figure 8 shows the AMESim model of boom and bucket valve.

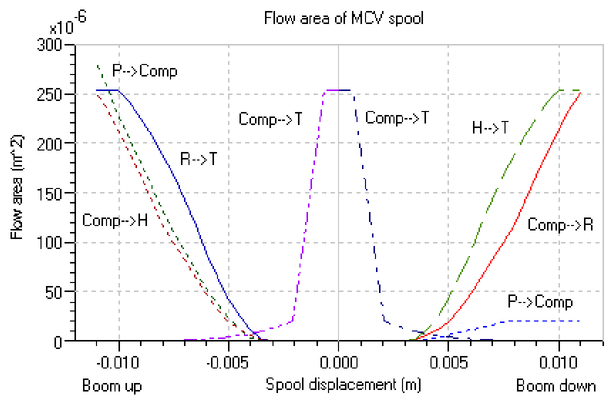

Fig. 6 Spool displacement-flow area characteristics of the boom valve

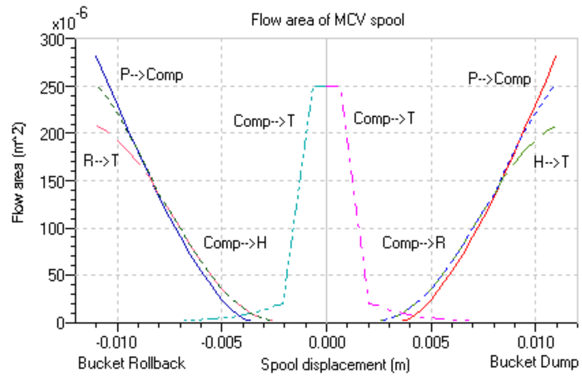

Fig. 7 Spool displacement-flow area characteristics of the bucket valve

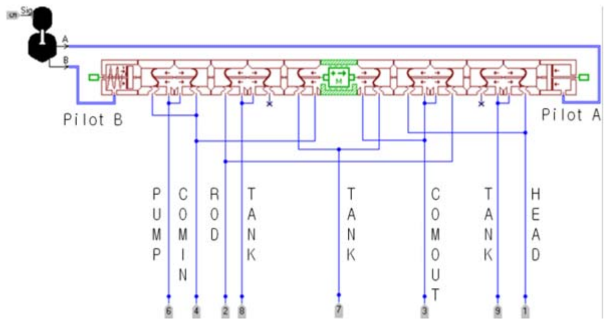

Fig. 8 Model of boom and bucket valve using AMESim

3.3 Joystick modeling

The employment of joystick has virtually replaced the traditional mechanical control lever in nearly all modern hydraulic control systems. Most of the movements of wheel loader are controlled with operation of joystick control lever. Joystick operation decides pilot pressure and direction of movements of MCV spools. The pilot pressure having range 0~45kgf/cm2 is used in this hydraulic system simulation model. This pressure acts on either side of MCV spools, results respective displacement of spools. Then hydraulic oil passes through the flow area generated by the movement of spools.

In this paper, the operating signal input to joystick is assumed between −10 to 10mA and the corresponding pilot pressure generated to port A and port B is directly proportional to the magnitude of input signal.

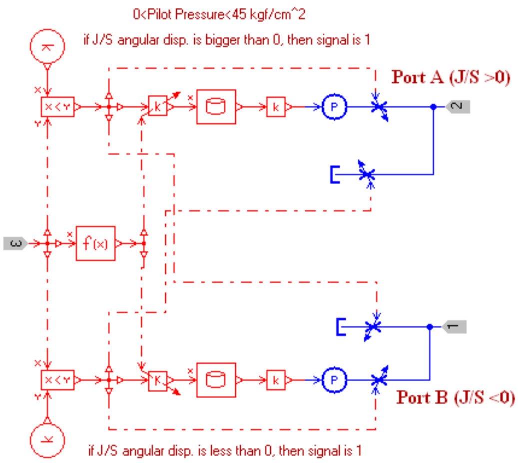

Fig. 9 Model of the joystick using AMESim

3.4 Compensator modeling

The compensator arranged downstream from the orifice (valve spool) is subjected to the pressure downstream from the respective orifice in the opening direction and in the closing direction to a pressure from the respective actuator. It keeps the pressure drop across the orifice constant, which keeps flow constant and thereby cylinder speed is constant independent of load. Figure 10 shows the hydraulic circuit model of compensator.

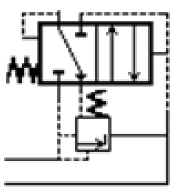

Fig. 10 Hydraulic circuit model of compensator

The compensator keeps the pressure in the

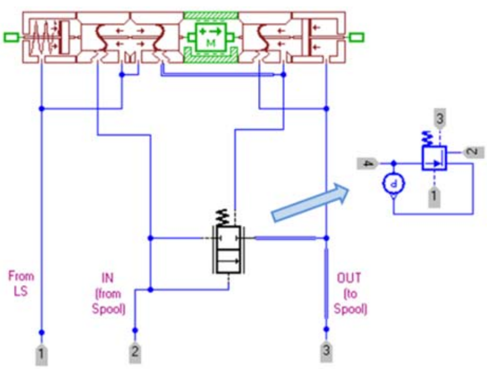

Fig. 11 AMESim model of compensator

pump line to a higher value than the highest load pressure by a pressure difference equivalent to the force of a control spring, so-called Δp control. The value of Δp is assumed to 20bar in this paper. Figure 11 shows the AMESim model of compensator.

3.5 Attachment modeling

There are several types of wheel loader implement linkages currently in use. A very common example, called the Z-bar linkage is shown in Fig. 12.

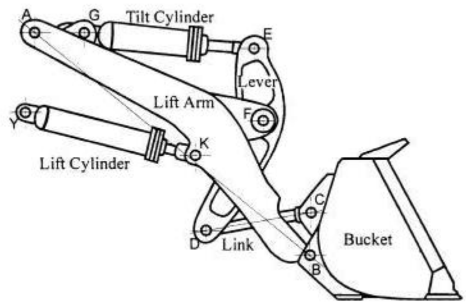

Fig. 12 Typical wheel loader attachment

It is a two degrees of freedom (dump and roll back) linkage consisting of four bodies (lifting arm, reversing lever, connecting link, and bucket) and two asymmetric hydraulic cylinders (lift and tilt), all connected together by nine revolute pin joints. The tilt and lift cylinders are double acting type and the specifications are shown in Table 1.

Table 1 Specifications of cylinders

Parameter	Lift cylinder	Tilt cylinder
Piston diameter	175mm	150mm
Rod diameter	50mm	55mm
Length of stroke	760mm	460mm
Freelength	1240mm	800mm

In the course of modeling of the Z-bar linkage using AMESim, the size and weight of the bodies are obtained from the specifications of a typical wheel loader. The position of the bodies has defined according to the relative coordinate system of the AMESim planar mechanical library.

In order to get actual animation at desired shape of the attachment, this model includes contour data of reversing lever, lifting arm and bucket that confirm the virtual movement of the attachment based on simulation result. Figure 13 shows the AMESim model of the attachment.

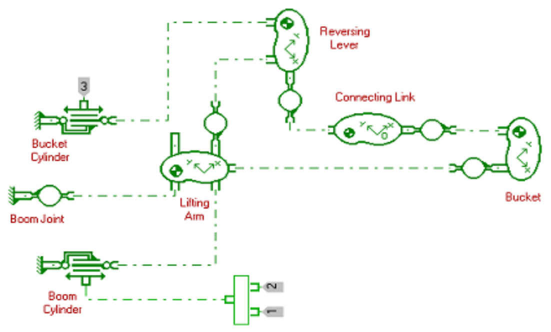

Fig. 13 Model of the attachment using AMESim

3.6 hydraulic system modeling

By a combination of models, including the model of pump, MCV, compensator and attachment, coupled with input signal, we get the complete simulation model of the wheel loader hydraulic system that illustrates in Fig. 14.

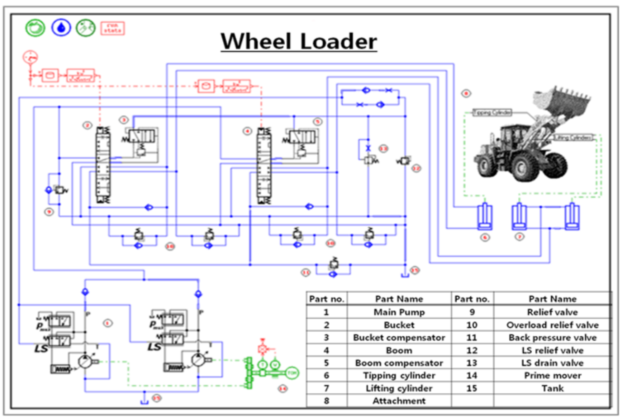

Fig. 14 Wheel loader hydraulic system simulation model using AMESim

And then, simulation is carried out to verify the effectiveness of the developed model when it is applied to wheel loader hydraulic system with different joystick input signals. An additional advantage of this model is that we can clarify the results more quickly and easily by the animation result.

4. Simulation and Results

The developed simulation model works according to the operation of joystick control lever that moves MCV spools. Considering virtual loading and unloading tasks, the operating signals input to joystick are -10 to 10mA for the purpose of simulating the behavior of the entire hydraulic system that illustrates in Fig. 15.

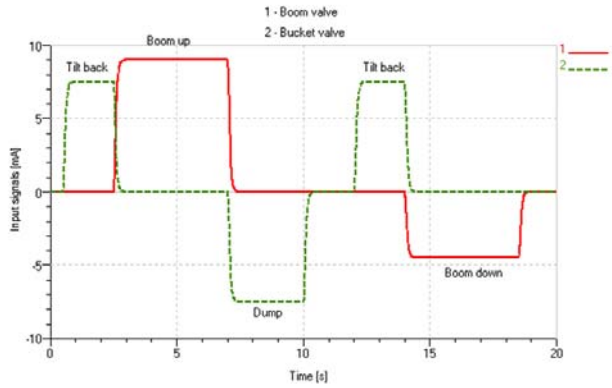

Fig. 15 Joystick signals

The movement of attachment according to input signals is decided same order as illustrates in Table 2.

Table 2 Cylinders movement with respect to input signals

Signal	Boom	Bucket
+ (positive)	up	tilt back
0 (zero)	hold	hold
– (negative)	down	dump

Based on existing typical wheel loader hydraulic circuit and relevant technical papers, we set the parameter values of the developed simulation model where several important values are introduced. Main relief valve keeps the maximum pressure in the system to 320bar. The over load relief valve, LS drain valve, LS relief valve and back pressure valve settings are 340, 255, 255 and 10bar respectively.

A variety of graphs are obtained from the simulation results. Figure 16 shows results for the main pump namely pump pressure and pump flow rate.

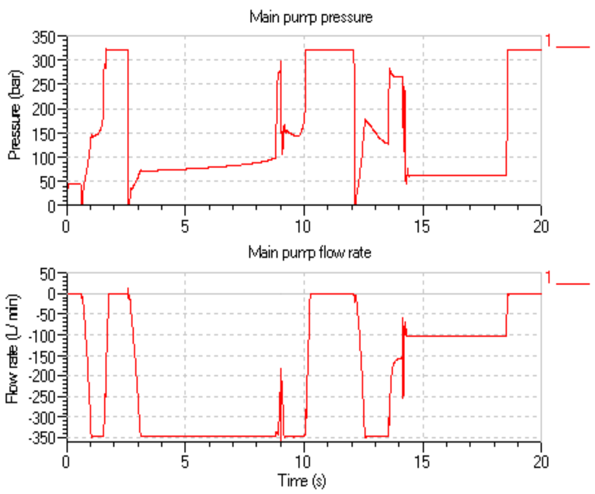

Fig. 16 Simulation results of main pump

Figures 17 and 18 show simulation results for the boom and bucket namely pilot pressure for valve operation, cylinder displacement, pressure and flow rate for the cylinder head and rod side respectively.

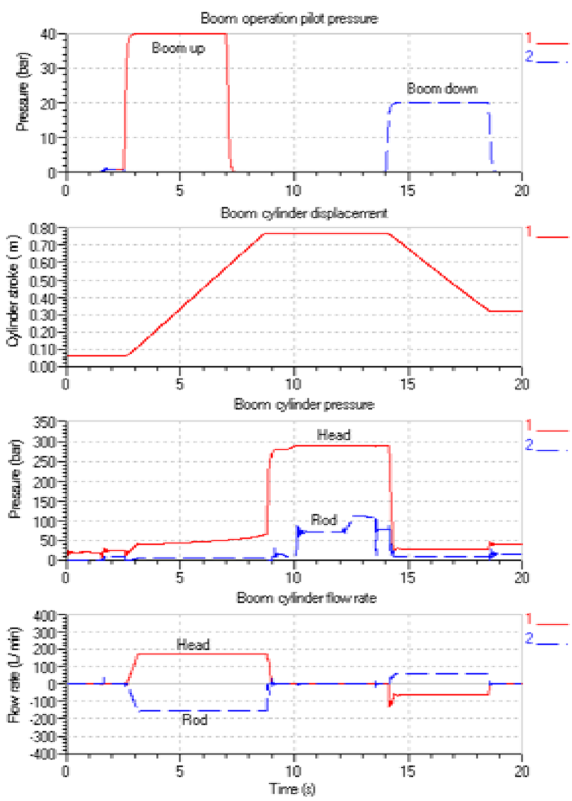

Fig. 17 Simulation results of boom

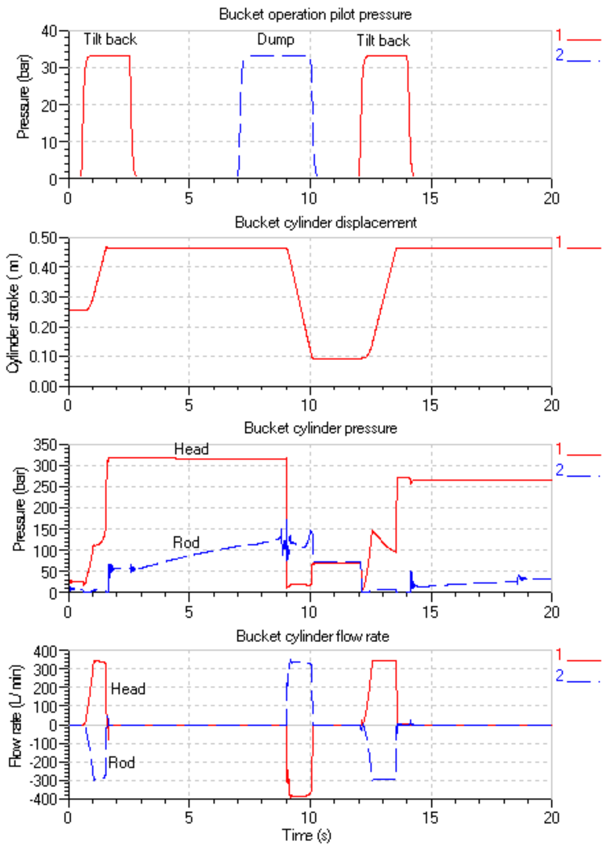

Fig. 18 Simulation results of bucket

In this model the value of Δp is set to 20bar and it is the compensators' job to fix the pressure drop across the orifice at 20bar. As the pressure drop is constant, the flow rate only depends on the valve position. This provides very precise control. Figures 19 and 20 show the pressure comparison across boom and bucket compensator respectively.

From the above figures., it is noticeable that the main variable pump adjusts pressure according to load-induced pressure fed back to the pump

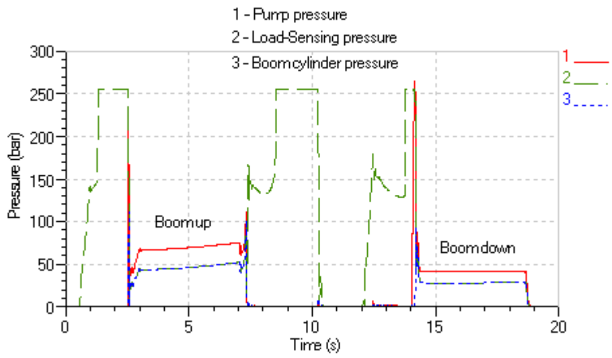

Fig. 19 Pressure comparison across boom compensator

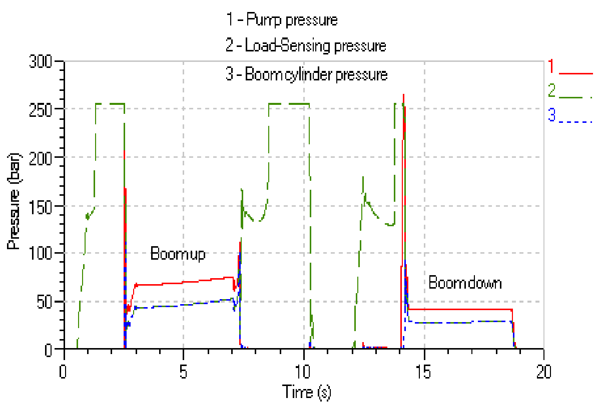

Fig. 20 Pressure comparison across bucket compensator

through load-sensing controller and maintains a higher value equivalent to Δp, thereby making the system energy efficient. Figure 21 shows compare the experimental results and simulation results. Experimental results and simulation results are very similar. Experimental condition is the boom in the state of no load pressure and measured the pressure at boom UP-DOWN.

From the figures 19-20, obviously, the simulation results and the field test result are almost consistent, so the model as illustrated in Fig. 14, is right.

We can further clarify the results of simulation of the developed model through AMEAnimation. Figure 22 illustrates the sequence of virtual loading and unloading task typically done by wheel loader obtained from animation result.

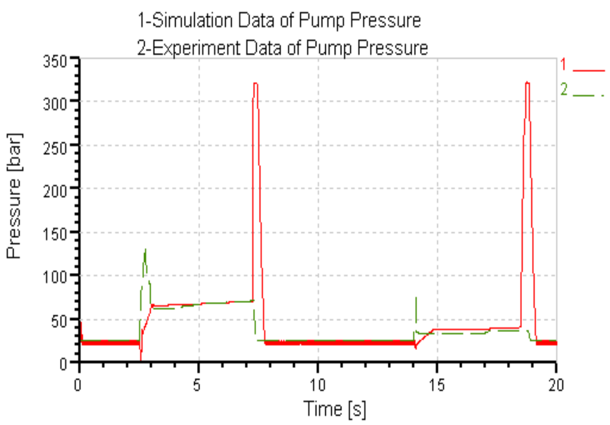

Fig. 21 Pressure comparison of experiment and simulation

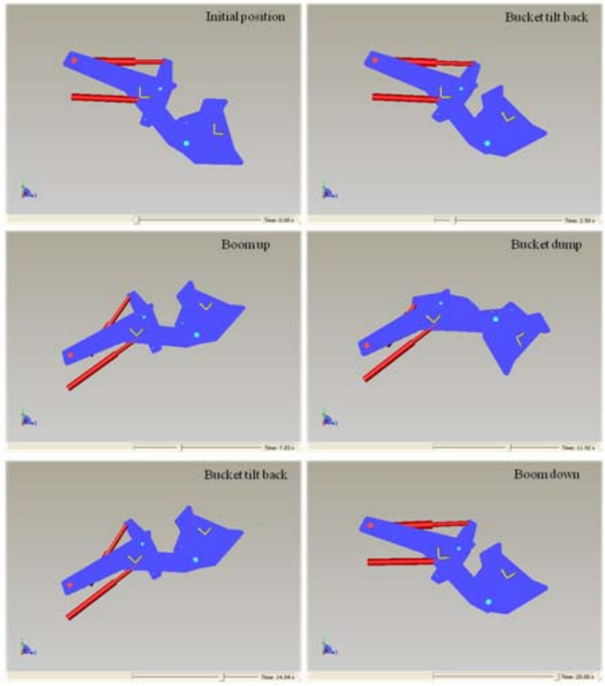

Fig. 22 Typical virtual loading and unloading task scenarios using AMEAnimation

5. Conclusions

The main features of this work can be summarized with the following key messages:

· This contribution presents a simulation model of hydraulic system for wheel loader that enables one to perform computer experiments at the first stage of design. Results of simulation can be used as initial data while building trial versions of real hydraulic system models.

· The simulation model can apply a platform in performance assessment of the wheel loader before building the prototype. Thus, eliminating the cost and time associated with building prototypes and improving design and operability of wheel loaders.

· The load-sensing hydraulic system of wheel loader is quite complicated and contains several feedbacks

In this respect it must be pointed out that the pressure drop across the orifice is not found exactly 20bar as set. A very precise parameter setting, especially for orifice areas of the MCV spools, is required to achieve exact pressure drop.

· Along this research frame, as a future step, we intend to further develop this simulation model so that it will be applicable to the performance test of hydraulic components and automation study of wheel loader. This will hopefully lead in the near future to a modeling tool capable of accurate portrayal of the wheel loader hydraulic system.

· The approach is original and there is difficult to find similar works. The methods of modeling and simulation possess universal significance to other related hydraulic systems.

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