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A HYDRAULIC SIMULATOR FOR AN EXCAVATOR

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ABSTRACT

An excavator consists of several hydraulic components which include pumps, a main control valve and cylinders etc. It operates by the linkage of the components. This paper is concerned with development of a hydraulic simulator for an excavator. The simulator has been developed using AMESim based on specifications of a 1.5 ton excavator. The excavator has been installed additional components to investigate an automated field robot; Electro proportional pressure reducing valve, electronic joysticks, angle sensors and a controller was installed at the excavator. The developed hydraulic simulator has the ability to represent with animation. The modeled MCV has been applied non-linear open area of spools.

KEY WORDS

Excavator, Simulation, AMESim, MCV

INTRODUCTION

The Hydraulic excavator has been the best popular construction equipment because of its multi-working ability in the construction field [1-2]. However its energy efficiency and prevention of environmental crisis are still need to improve.
The capabilities of controllers and components have been tested at the excavator directly. However, these tests accompany with lots of time, risk, resources. In order to develop efficiently, simulation is necessary before the test.
This paper describes the hydraulic simulation of excavators. Components and hydraulic system are built using the AMESim.

MODELING OF COMPONENTS

In order to develop the hydraulic simulator, first each component was modeled. MCV, Joysticks, attachment were newly modeled in this paper. These component modeling are based on 1.5 ton hydraulic excavator.

Main Control valve
The MCV consists of various valves for boom, arm, bucket, travel motor, dozer and swing etc. Only the valves of boom, arm and bucket are considered in this paper.
These valves are 6 ports 3 position types including bypass circuits. The Fig.1 is shown a circuit diagram of a boom valve. When spool is in neutral, the bypass line

is completely open. If pilot pressure act to one side of a valve selectively, spool is moved in accordance with the pressure. Then the open-area shows a non-linear relation with spool displacement as same to the Fig.2.

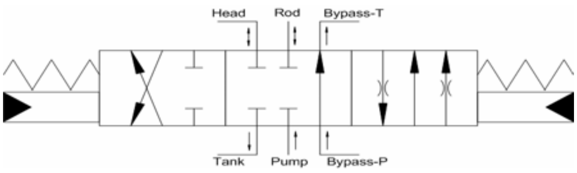

Figure 1 Circuit diagram of the boom valve

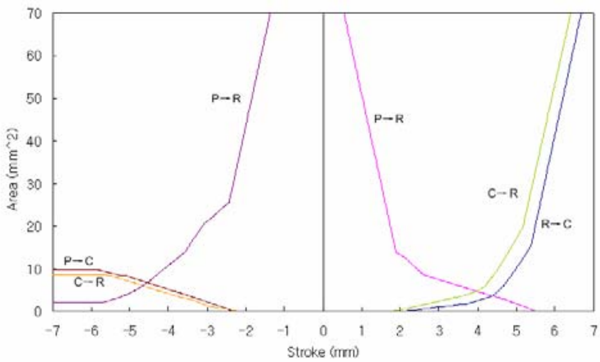

Figure 2 Stroke-Open area characteristics of boom valve

The boom valve was designed in order to include the direction of spool and non-linear open-area using the AMESim as shown in Fig. 3.

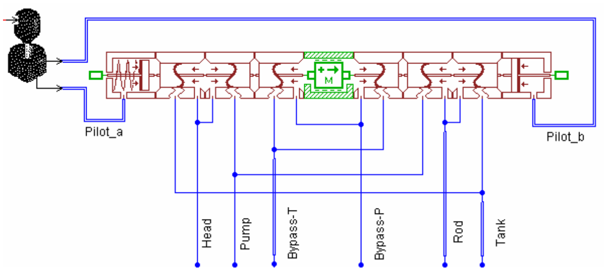

Figure 3 Modeling of the boom valve using the AMESim

Joystick

As for most movements of excavator, it is acted with operations of joysticks. The operations decide on pilot pressure and direction. The pilot pressure having range of $0 kg/cm^2$ to $20 kg/cm^2$ are used. These pressure and direction move spools of the MCV, then hydraulic oil pass through open-area which are generated by the movement of spools.

In this paper, operating of joysticks is assumed to signal between -1 to 1 and pilot pressure to A, B port is directly proportional to signal. The models of joysticks are same to Fig. 4.

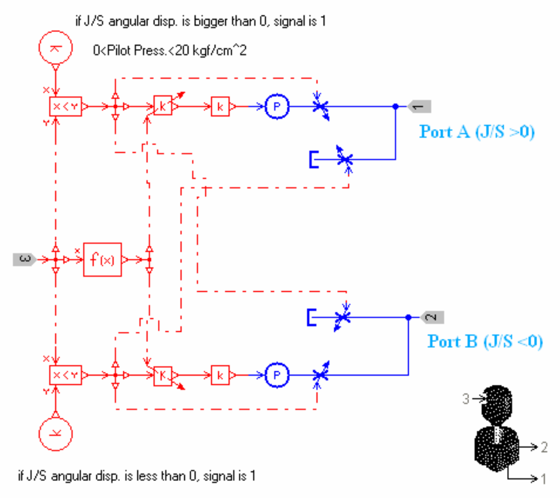

Figure 4 AMESim model of the joystick

Attachment

The size and weight of attachment was obtained by making an actual survey.

In order to start the simulation at wanted shape of the attachment, the initial angular position of boom, arm and bucket had to be decided. It needed to obtain the geometry modeling.

A coordinate system was determined with 3 degrees of freedom as shown in Fig. 5. Although the relative angular position of each component has used generally to study about an excavator [3-5], the absolute angular position which is suitable for the modeling using the AMESim has been used in this paper.

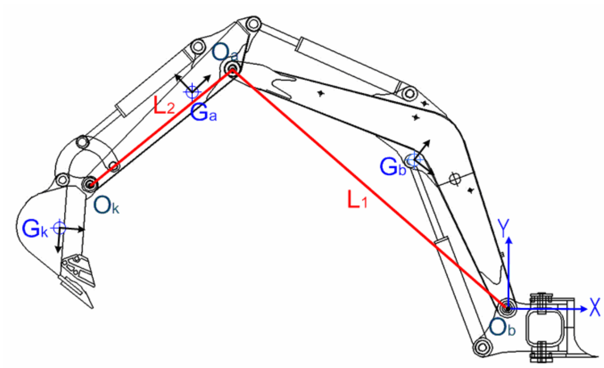

Figure 5 Coordinate system of the attachment

The joints of boom, arm and bucket are denoted as $O_b(x_b, y_b)$, $O_a(x_a, y_a)$ and $O_k(x_k, y_k)$. Their points are obtained using Eqs. (1) ~ (3).

$$x_b = 0,$$
$$y_b = 0, \quad (1)$$

$$x_a = -L_1 \times \cos\theta_b ,$$
$$y_a = -L_1 \times \sin\theta_b , \quad (2)$$

$$x_k = -L_1 \times \cos\theta_b - L_2 \times \cos\theta_a ,$$
$$y_k = -L_1 \times \sin\theta_b - L_2 \times \sin\theta_a . \quad (3)$$

where θ_b, θ_a are the absolute angular positions of boom and arm.

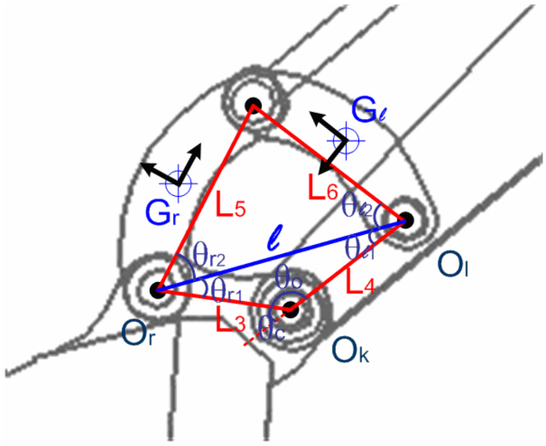

Figure 6 Four-bar linkages system

Fig. 6 shows the four-bar linkages which contain arm, bucket, control link and control rod. Eq. (4) is shown the coordinate point of a joint which connect arm and control link, and Eq. (5) is represented a joint which connects bucket and control rod.

$$x_l = -L_1 \times \cos\theta_b - (L_2 - L_4) \times \cos\theta_a ,$$
$$y_l = -L_1 \times \sin\theta_b - (L_2 - L_4) \times \sin\theta_a , \quad (4)$$

$$x_r = -L_1 \times \cos\theta_b - L_2 \times \cos\theta_a - L_3 \times \sin(\theta_c - \theta_k) ,$$
$$y_r = -L_1 \times \sin\theta_b - L_2 \times \sin\theta_a - L_3 \times \cos(\theta_c - \theta_k) . \quad (5)$$

where θ_k is the absolute angular position of bucket.

The distance l of O_l and O_r is same to Eq. (6).

$$l = \sqrt{(x_l - x_r)^2 + (y_l - y_r)^2} . \quad (6)$$

The initial angular position of the control link and control rod can be calculated using the second law of cosines as shown in Eqs. (7) ~ (8).

$$\theta_{l1} = \cos^{-1}\left(\frac{l^2 + L_4{}^2 - L_3{}^2}{2 \times l \times L_4}\right),$$
$$\theta_{l2} = \cos^{-1}\left(\frac{l^2 + L_6{}^2 - L_5{}^2}{2 \times l \times L_3}\right),$$

$$\theta_{r1} = \cos^{-1}\left(\frac{l^2 + L_3{}^2 - L_4{}^2}{2 \times l \times L_3}\right),$$
$$\theta_{r2} = \cos^{-1}\left(\frac{l^2 + L_5{}^2 - L_6{}^2}{2 \times l \times L_5}\right),$$

$$\theta_o = \cos^{-1}\left(\frac{L_4{}^2 + L_3{}^2 - l^2}{2 \times L_4 \times L_3}\right),$$

$$\theta_l = -\{(180 - \theta_a) + \theta_{l1} + \theta_{l2}\}, \quad (7)$$
$$\theta_r = \theta_a + \theta_o - (180 - \theta_{r1} - \theta_{r2}) . \quad (8)$$

The attachment was modeled using these equations and measuring data as shown in Fig. 7. This model includes contour data of boom, arm and bucket, so we can confirm the virtual movement of the attachment through simulation result.

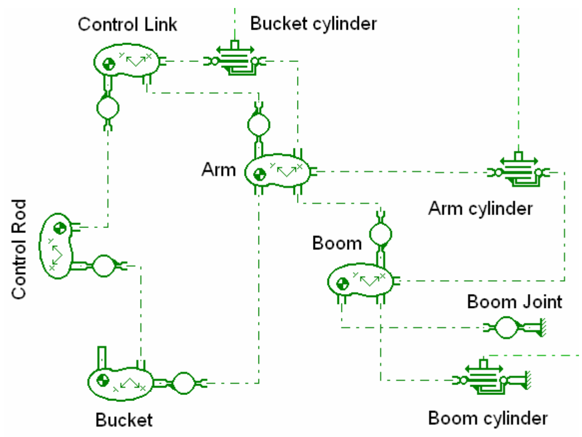

Figure 7 Attachment model using AMESim

Pump

An applied excavator has got three hydraulic pumps. One pump was already shown in Fig 4. The pump is used to control pilot pressure. The orders are fixed capacity type each flowing out 5.1cc/rev. A pump1 mainly take charge of the movement of the arm. And a pump2 usually concern with motion of boom and bucket. When the cylinder need much flow rate, pump2 can concern with the operation through a check valve.

Cylinder

Attachment is moved by stroke variation of three cylinders. The specification of cylinders is the same to Table 1. In this study, the weight of cylinders has been ignored.

Table 1 specification of cylinders

	Boom	Arm	Bucket
Piston diameter	55mm	55mm	55mm
Rod diameter	30mm	30mm	30mm
Length of stroke	0.38m	0.39m	0.3m
Free length	0.62m	0.62m	0.52m

MODELING OF SYSTEM

The hydraulic simulator system for the excavator was completed by assembly of each component. The models of the attachment and valves are setting up to each separate subcomponent.

This simulator system works according to input signals having range of -1 to 1 which they move valve spools. Relief valves set up the maximum pressure in the system to 210 kg/cm^2. Fig.8 shows the hydraulic simulator system using the AMESim. Two pumps turn to the same speed because they are connected with the only engine. And the flow rates are also same.

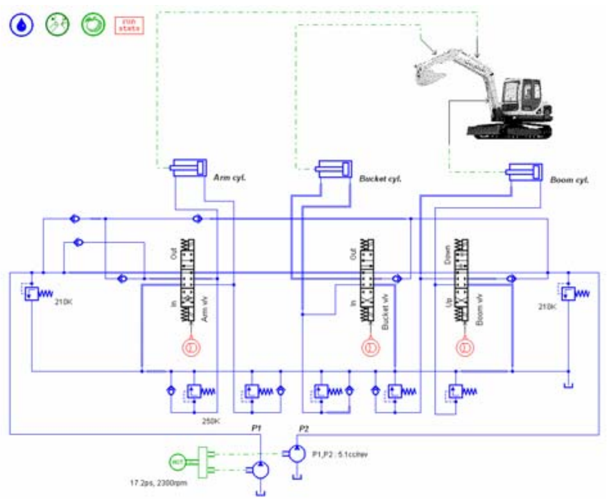

Figure 8 Circuit diagram of simulator using the AMESim

EXPERIMENT

We assumed to work excavation and then the signals were inputted to each valve. An engine speed was supposed to 2300rpm. Then the input signals are same to Fig. 9.

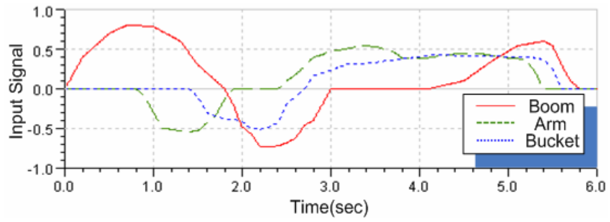

Figure 9 Joystick signals

The moving direction of attachment according to input signal was decided the same to Table 2.

Table 2 Input signal-moving direction characteristics

	Boom	Arm	Bucket
+ (positive)	up	crowd	crowd
- (negative)	down	dump	dump

When input signals are the same to Fig. 9, each cylinder stroke is appeared as shown in Fig. 10.

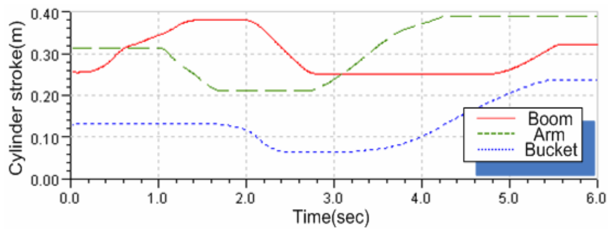

Figure 10 Cylinder strokes

Fig. 11 shows the relative angular positions and Fig. 12 shows the absolute angular positions of the attachment.

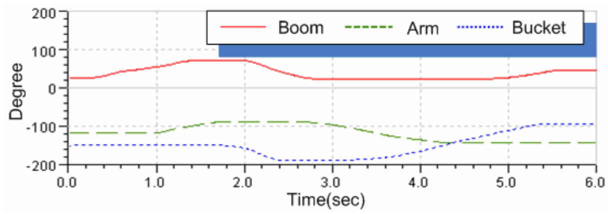

Figure 11 Relative angular positions

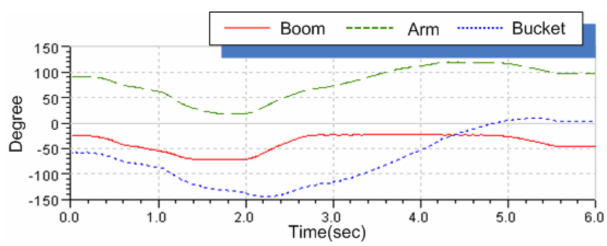

Figure 12 Absolute angular positions

The pressure at both ends of cylinders is also obtained by this simulation as shown Fig. 13.

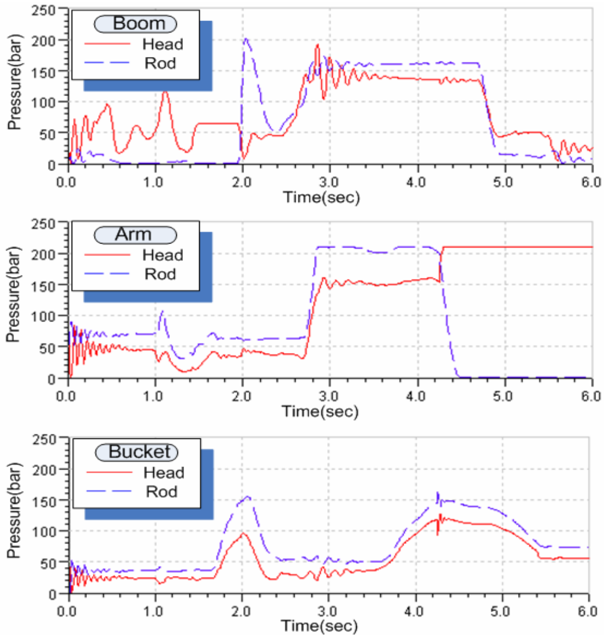

Figure 13 Cylinder Pressure

This hydraulic simulator calculates not only above-mentioned things, but also many other thing, trajectory, flow rate, shaft torque etc. Fig. 14 shows the flow rates at both ends of cylinders in the same simulation.

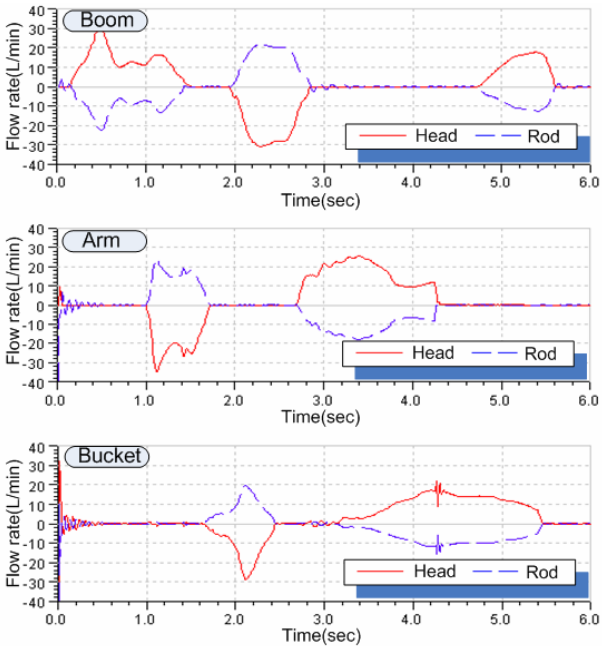

Figure 14 Flow rate at ports of cylinders

The simulation was operated and we obtained the results of that. We can confirm the results more quickly and easily by an animation function. Fig. 15 is a scene of the animation based on the results of the excavation work.

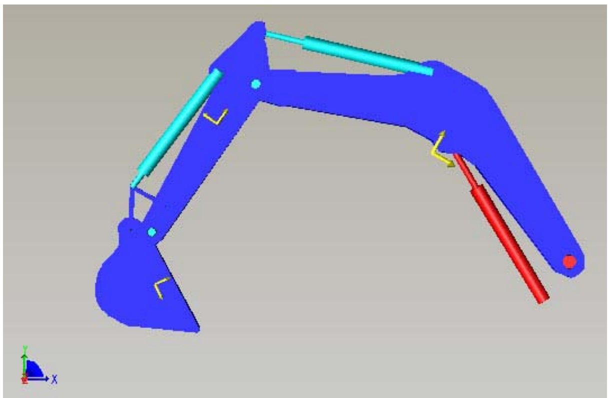
Figure 15 A scene of animation

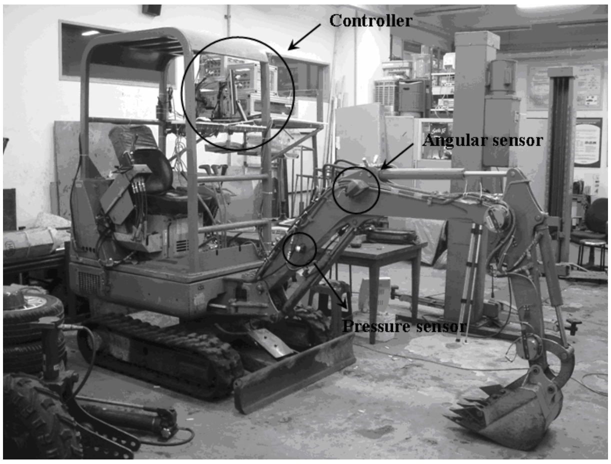

Figure 16 A photo of the applicatory excavator

CONCLUSIONS

In this study, the hydraulic simulator is developed for the excavator. The mechanicals have been modeled in accordance with the specifics and measuring of the excavator. The input signal into the MCV can be controlled in the simulator. Because the MCV model includes a characteristic of non-linear open-area in accordance with displacement of spools, it is more effective than other studies which use feed-back system with linear open-area valve.

Various results are obtained by the virtual excavation work.. We are going to measure the pressure and angular positions using the excavator as shown in Fig. 16. The measuring data and results of simulation will be compared each other to evaluate the simulator.

After rectification and supplementation, it is expected that this hydraulic simulation program are applied automation study, performance test of component etc.

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