Development of AMESim Model of Main Control Valve for Hydraulic Excavator

Tae-Hyeong Lim*, Soon-Yong Yang, Byung-Ryong Lee and Kyung-Kwan Ahn**

* Department of Mechanical & Automotive Engineering , University of Ulsan, Ulsan, Korea
(Tel : +82-52-259-2731; E-mail: bulbaram@mail.ulsan.ac.kr)
**School of Mechanical & Automotive Engineering, University of Ulsan,Ulsan,Korea
(Tel : +82-52-259-2820; E-mail: soonyy@mail.ulsan.ac.kr)

Abstract: The hydraulic excavator has been a popular research object for automation because of its multi-workings and economic efficiency. The objective of this paper is to design each components and to construct boom, arm, bucket circuit. These models modeled with AMESim show us change of variables and behavior of excavator. Simulation model will be used for simulator of excavator.

Keywords: Hydraulic Excavator, AMESim, Main Control Valve, Attachment, Hydraulic circuit

1. INTRODUCTION

Hydraulic excavator has been applied to many field because of flexibility like a human arm and high performance of hydraulic actuator. It is typical application that Construction, agriculture, undersea etc. Hydraulic excavator is made up 60% of whole construction instruments.

Construction of mathematical equation is very difficult because excavator is heavy system, unsymmetrical single rod cylinder, saturation and dead zone of control valves.

If system identification method is used to model of hydraulic circuit with experimental data, construction of mathematical equation is to be easy but can not observe change of inner parameters.

In this paper, each component of excavator – pump, main control valve, cylinders, external force on cylinder – are modeled with AMESim. Each AMESim models construct total hydraulic circuit of excavator.

Suitability of AMESim model is verified by comparing with experimental results. Simulation has taken under same working condition with experiment.

It is impossible that we attach sensors to observe change of whole parameters. AMESim model help that.

2. MODELING OF HYDRAULIC CIRCUIT

Hydraulic circuit is made up pump, Main Control Valve(below MCV) block, Cylinders. Pump make up main pressure and pilot pressure. When lever is operated, MCV is forced at a section by pilot pressure. Main pressure is put into cylinder by Movement of MCV. Each attachment – Boom, Arm, Bucket – can work with main pressure.

In this paper, there are assumptions for simplication.

(1) Bulk modulus is constant.
(2) Change of density and viscosity of working oil by effect of temperature is ignored.
(3) Loss in pipe and hose is ignored.
(4) Working range is 2 dimensional plane with boom, arm, bucket.
(5) Confluence, holding valve is ignored.

Hydraulic circuit with assumption is appeared Fig. 1. ① is pump, ② MCV block is in red dotted box is, ③, ④, ⑤ is cylinders.

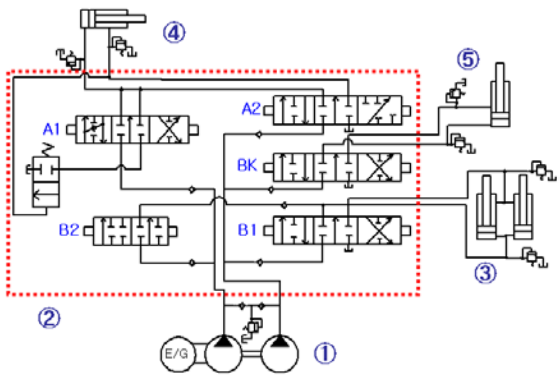


Fig.1 Simplified hydraulic circuit of hydraulic excavator

B1 and A1 valve control boom and arm cylinder mainly. B2 and A2 valve send flow to support Boom up and Arm in, out. BK valve control bucket cylinder because Bucket cylinder don't require a lot of flow. And regeneration circuit is included to circuit. Regeneration circuit can prevent sudden dropping of arm and send flow to arm cylinder.

After this, each components will be modeled with AMESim and each AMESim model consist of total hydraulic circuit.

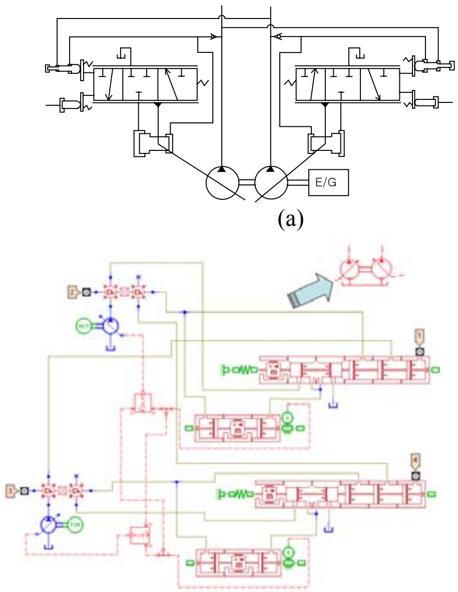
2.1 Pump

Flow from two axial piston pump is controlled by total horse power and flow control diagram.

Fig. 2 (a) show hydraulic circuit of pump and regulator. Engine offer a torque to pumps and regulator control swashplate angle of pump. Fig. 2 (b) is AMESim model of pump and regulator and its super-component in AMESim. Super-component is a package of many components.

2.2 Electronic Proportioning Valve

Hydraulic Joystick have to replaced to Electronic Joystick for automation of excavator. For control of direction and magnitude of pilot pressure, electronic proportioning valve block have to be attached.



(a)

(b)

Fig.2 Pump and Regulator

(a) Hydraulic symbol

(b) AMESim model and super-component

In automation of excavator, if electronic joystick is operated joystick make up a current in proportion to angular displacement. Current is delivered to electronic proportioning valve. Valve can control direction and magnitude of pilot pressure.

In simulation, angular displacement of electronic joystick is replaced to signal. Electronic proportioning valve is modeled to 4 port 3 position valve. Fig. 3 show AMESim model of electronic proportioning valve.

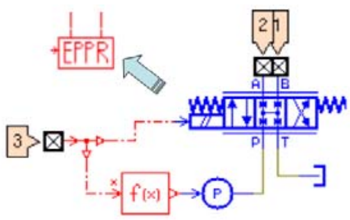


Fig.3 AMESim model of Electronic Proportional Valve

2.3 Main Control Valve

Main Control Valve is made up of B1, A1, BK, B2, A2 valve. B1, A1, BK valve control each cylinder mainly and B2, A2 valve support insufficient flow to cylinder. Valve is characterized with open area-stroke diagram. Open area is determined by stroke of spool. But diagram have high nonlinearity because of dead zone and saturation that is set for feeling of operator. Nonlinearity is made by notch at land of spool and seat.

Each valve has different open area-stroke diagram and Fig.4 is Boom1 valve's diagram.

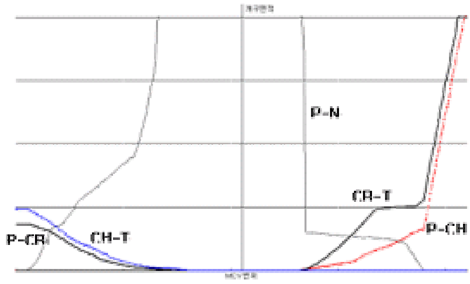


Fig.4 Open area vs stroke characteristic diagram of Boom1 valve

2.3.1 Boom1 valve

B1 valve is modeled 6 ports 3 position valve having 5 lands. Real parameters is put into Each port and spring with data file. It is more efficient for application to simulator.

Fig. 5 show that AMESim model and super-component of Boom1 valve.

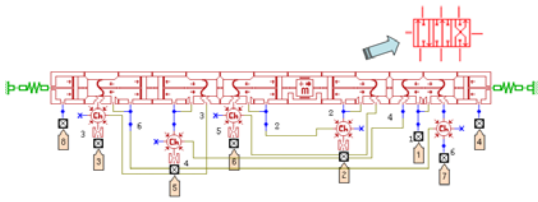


Fig.5 AMESim model of Boom1 valve

2.3.2 Boom2 valve

B2 valve is modeled 4 port 2 position valve and work in boom up that support insufficient flow. AMESim model is shown in Fig. 6.

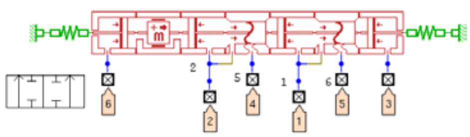


Fig.6 AMESim model of Boom2 valve

2.3.3 Arm1 valve

A1 valve is modeled 6 port 3 position valve and is included regeneration circuit preventing a sudden dropping of arm and supporting insufficient flow at Arm in. Fig. 7 show AMESim model.

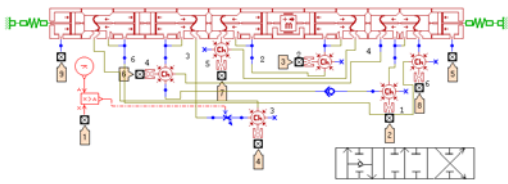


Fig.7 AMESim model of Arm1 valve

2.3.4 Arm2 valve

A2 valve is modeled 6 port 3 position valve and support insufficient flow. Fig. 8 show AMESim model.

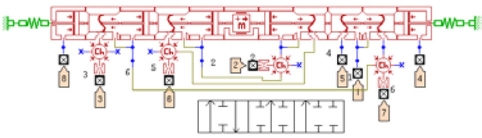


Fig.8 AMESim model of Arm2 valve

2.3.5 Bucket valve

BK valve has same structure with Boom1 valve but different open area-stroke diagram.

2.4 Cylinder

Boom has two single rod cylinder and arm, bucket has one cylinder. Cylinder is modeled simple single rod cylinder without Coulomb friction and leakage. Fig. 9 show AMESim model of Boom cylinder.

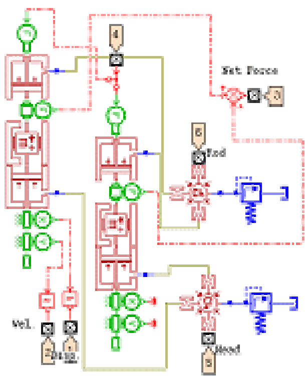


Fig.9 AMESim model of Boom cylinder

2.5 Total hydraulic circuit

Hydraulic circuit shown Fig. 1 is rebuild AMESim model in Fig. 10.

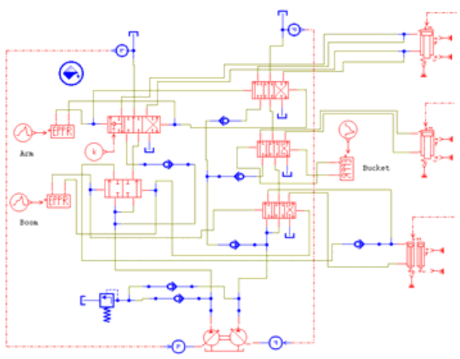


Fig.10 AMESim model of hydraulic circuit of hydraulic excavator

3. CYLINDER FORCE

As cylinder move linear, attachments have rotational movement with each coupling point. Weight of attachment give a force to cylinder.

External force to Boom cylinder is sum of boom, arm and bucket weight. Fig. 11 show this.

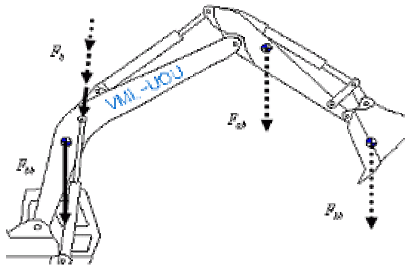


Fig. 11 Cylinder force of boom cylinder

$$F_b = F_{bb} + F_{ab} + F_{kb}$$

$F_{bb} = m_b g \cos\eta_{bb}$ is a force from boom weight. η_{bb} is angle with direction of weight and cylinder.

4. SIMULATION RESULT

4.1 Specification of excavator

The weight of Hydraulic excavator in this paper is 21 ton. Specification of excavator is shown Table 1.

Table 1 Specification of hydraulic excavator.

General	density	Kg/m3	890	
	Bulk modulus	bar	7000	
	Coefficient	0.61		
Hydraulic		Boom	Arm	Bucket
Head	Diameter	120	140	125
	Cracking P	300	300	300
	Max. P	320	320	320
Rod	Diameter	82	100	85
	Cracking P	300	300	260
	Max. P	320	320	280
Stroke		1290	1510	1055

4.2 Working condition

To compare with experimental data working condition have to be same. Working condition is explained blow.

(1) Boom

Boom up for 4 sec. and boom down for 4 sec. with fixing arm and bucket.

(2) Arm

Arm in for 4 sec. and arm out for 4 sec. with fixing boom and bucket.

(3) Bucket

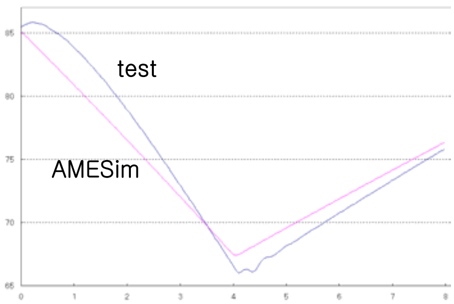
Bucket in for 4 sec. and bucket out for 4 sec. with fixing boom and bucket.

4.3 results

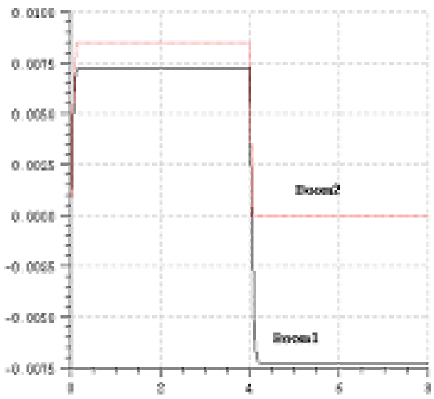
Results from simulation and experiment under condition at 4.2 are compared with in Fig. 12 and Fig. 13.

Fig. 12 show Boom results. (a) show angular displacement in boom joint. As we know, Characteristics at up and down are different from each other and flow at head and rod are different. However be same for time up and down, angular displacement is different each other. Oscillation in the vicinity of 4 sec is from inertia of arm and bucket and looseness.

(b) show stroke of B1 and B2 valve. Different of spring coefficient, stroke is different from each other. And stroke of B2 valve don't be shown boom down.

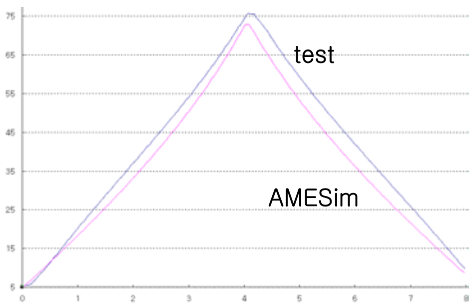


(a)

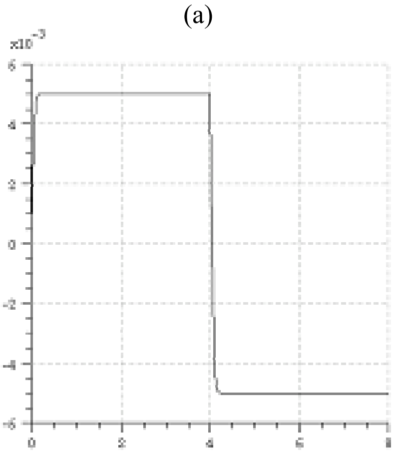


(b)

Fig.12 Simulation Results of Boom
(a) angular displacement of boom (b) spool displacements



(a)



(b)

Fig.13 Simulation Results of Bucket
(a) angular displacement of bucket
(b) spool displacement

Fig. 13 show bucket result. (a) show angular displacement of bucket joint. Bucket don't influenced by boom and arm graph is similar and there is no oscillation. (b) show stroke of BK valve.

5. CONCLUSION

As a preceding research of automation of excavator, each component of hydraulic circuit is modeled with AMESim. This models consist of hydraulic circuit and simulation is taken under experimental working condition.

1. AMESim model of Axial piston pump, Main Control Valves, electronic proportional valve, Cylinder are constructed.

2. Behavior of simulation and experimental are similar. It is possible that obtain unknown parameters.

3. AMESim circuit will be used a simulator of excavator.

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