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STUDY ON HYBRID MODELING OF HYDRAULIC EXCAVATOR

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ABSTRACT

Hydraulic excavator is a very complex plant integrated with mechanical, hydraulic and control systems. To study on such a complex system, one must have the related multidisciplinary knowledge. This paper presents a new research method for hydraulic excavator by introducing a hybrid model based on AMESim and a complete model of an excavator was made in order to analyze the command law for the excavator.

1. Introduction

Hydraulic excavator is a very complex plant integrated with mechanical, hydraulic and control systems. It is necessary to develop a hybrid model to evaluate performances of working in multi physical domain. To date, many kinds of models were built for excavators [1,2]. Most of them are based on single physical domain, such as hydraulic model, mechanical model [3]. It is hard to simulate the comprehensive characteristics for excavators. Currently, the AMESim tool provides a series of new sub-models related with multi physical, multi- dimension technologies [4-5].

This paper presents a new simulation method base on AMESim tool to build a research platform for hydraulic excavators. It should contain mechanical, hydraulic and control system together to describe a complete model of an excavator.

2. ARCHITECTURE OF HYDRAULIC EXCAVATOR

Excavators are heavy construction equipment consisting of a boom, stick, bucket and cab on a rotating platform known as the house. The house sits atop an undercarriage with tracks or wheels. Fig depicts the mechanical architecture of excavators. The two main sections of an excavator are the undercarriage and the house. The undercarriage includes the blade (if fitted), tracks, track frame, and final drives, which have a hydraulic motor and gearing providing the drive to the individual tracks, and the house includes the operator cab, counterweight, engine, fuel and hydraulic oil tanks. The house attaches to the undercarriage by way of a center pin.

Engines in hydraulic excavators usually just drive hydraulic pumps; there are usually 3 pumps: the two main pumps are for supplying oil at high pressure for the arms, swing motor, track motors, and accessories, and the third is a lower pressure pump for Pilot Control, this circuit used for the control of the spool valves, this allows for a reduced effort required when operating the controllers. Figure 2 is a scheme of hydraulic circuit for an excavator.

Figure 1: Mechanical architecture of excavators

Figure 2: Scheme of hydraulic circuit and its controller of excavators

2.1 Hybrid Modeling with AMESim

In order to establish a hybrid model for hydraulic excavator, the mechanic system, hydraulic system and the control system should be modeled respectively. Still, the parameter transferring process between systems should also be modeled. Usually, the mechanic model should aim at the dynamic characteristic. The hydraulic model should model the power transfer functions and the control model describes the control algorithms or theories. The most important one is trying to figure out the parameter transfer process, because the mechanic system is a 3D model while the other two are 1D models.

2.2 Mechanical system modeling

The excavator core mechanism model can be seen as a complex "inertia" element. With this respect, the body kinematics are computed by the component and are thus outputs of the model. AMESim provides a 3D sub-model of 9-DOF (Degree Of Freedom) mechanism representing the mechanical system which is shown in Figure 3.

Figure 3: 9-DOF mechanism to represent excavator mechanical system

2.3 Hydraulic system modeling

The hydraulic system is composed of pumps, control valves and cylinders. To simplify the model, the pump is considered as a fixed pressure hydraulic power source. The control valve is a simple sub-model of a 4 ways 3 position hydraulic servo valve as shown in Figure 4. The spool dynamics is modeled as a 2nd order system with a specified natural frequency and damping ration. The inner parameters of control valve are set according to SM12 whose parameters are shown in Table 1.

Table 1: Parameters of control valves-SM12

Maximum Pressure	Pilot Pressure	Leakage(21MPa,40mm ² /s)	Viscosity	Temperature
35 MPa	3.5 MPa	50cm ³ /min	10~380 mm ² /s	-20~80°C

Figure 4: The model and parameters for the control valves

2.4 Control system modeling

The control system includes the four-actuator control. Usually, the actuators are controlled by using PID controller, which output v is of the form of Equa.1.

$$v = K_p \cdot u + K_i \cdot \int_{t_{start}}^t u \cdot dt + K_d \cdot \frac{\partial u}{\partial t} \quad (1)$$

2.5 Inter-action between 1D and 3D

Fig shows the 1D sub-model of an actuator of the exactor including hydraulic and control parts. The parameters should connect with that of the 3D mechanic parts shown in figure 3. AMESim provides several elements to connect 1D model with 3D model. Figure 6 shows two of them. TRVDNODE01 sub-model is a generic 3-dimensional mechanical junction. It receives kinematic elements at port 6 (displacement, velocity, acceleration - translation and rotation) and several motors (forces and torques) at port 1, 2, 3, 4 and 5. The outputs are the kinematic elements at port 1 to 5 (evaluated in another point of the solid) and complete motor (force and torques) at port 6 due to the several motors at port 1 to 5. TRVDCONV3D1D1 sub-model is a mechanical converter allowing 1D mechanical component to be connected to 3D bodies. It performs the computation of relative kinematics - linear and angular velocities and displacements - of the 3D elements connected at port 1 and port 5:

Figure 5: 1D sub-models of excavator

Figure 6: Elements for inter-action between 1D and 3D

3 SIMULATIONS WITH MULTI-PHYSICAL DOMAINS

By modeling the 3 parts of system, the hybrid models were built up. It is shown in Figure 7. It can be seen from Figure 7 how the three sub-models are connected together to form a hybrid model and how the signals are transferred through each other.

Before simulation, the physical parameters must be set first. A 36-ton excavator is chosen to be the reference. Its main parameters are as in table 2.

Table 2: Parameters of a 36-ton excavator

Weight	36800 Kg	Bucket capacity	1.7 m ³	Boom length	6.45 m
Stick length	3.2 m	Bucket Length	3.2 m	Swing Speed	9.7 RPM

The operating signals are given as the target position of the four actuators. The PID controller tries to keep the actuators moving along the target line. The tracks of each actuator are shown in Figure 8. Figure 9 shows the pressure change in each cylinder and Figure 10 shows the output force of each actuator.

Figure 7: Hybrid model for hydraulic excavator

(a) Boom

(b) Stick

(c)Bucket

(d) cab

Figure 8: The control signal and its control performance

(a)Boom

(b) Stick

(c)Bucket

(d) cab

Figure 9: The pressure of each cylinder

(a)Boom

(b) Stick

(c)Bucket

(d) cab

Figure 10: The output force of each actuator

4 CONCLUSIONS

The hybrid model of hydraulic excavator is composed of mechanical system, hydraulic system and control system. From the simulation results of a 36-ton excavator, it can be concluded that the established model can simulate the performance in multi-domains. After validating by experiments, the hybrid model can be used to evaluate the design of excavator and to re-evaluate the existed products.

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