Active Vibration Control of Excavator Working Equipment with ADAMS

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ABSTRACT

Hydraulic systems are utilized extensively as a method for controlling the distribution of energy within complex construction machinery. In this paper, ADAMS is employed to build a prototype of hydraulic excavator including the link mechanism of excavator working equipment and the hydraulic sub-system. The sub-systems are connected with loads, displacement, velocity and acceleration of cylinders. And more, an additional servo valve is added into the hydraulic sub-system to realize the active control of excavator working equipment vibration. In this paper, a numerical simulation test under various position of working equipment will be done, wherever the vibration is reduced effectively. The numerical simulation demonstrates the method in this paper can effectively reduce the harmfulness to operator by structural vibration.

1. Introduction

Nowadays, construction machinery manufacturers tend to develop products with low vibration, low noise and low exhaust air pollution. However, by the recent trend of high performances at bearing and efficiency, the boom structures of construction machinery tend to be larger and heavier than the current type. Such design policy causes instability in the entire body, and especially causes boom vibration in the low frequency below 10 Hz, which are very harmful to the operator. Hence, this vibration has had to be reduced substantially. Very troublesome it is to control this vibration by any passive techniques to cater for the design requirement of construction machinery, which demand products to be flexible, energy saving and long life. In such a situation, an active control system of boom vibration with the use of hydraulic servomechanism will certainly be a nice choice.

Hydraulic excavator is an entity coupling with mechanical and hydraulic systems, and the vibration is related to working equipment's attitude and environmental loads. In order to evaluate its vibration characteristic during design cycle, a visual prototype of hydraulic excavator should be built at first, which includes hydraulic system and mechanical system. However, the conventional simulation software cannot combine hydraulic system with mechanical system ideally. Furthermore, it is difficult to evaluate the loads acted on the whole system by manual also. Therefore, it is arduous to obtain a perfect analysis results erenow. However, ADAMS software product, which is used extensively for the dynamic simulation of complex mechanical system, can be utilized to generate such an excavator prototype easily.

2. Generation of excavator prototype

2.1 Mechanical system model

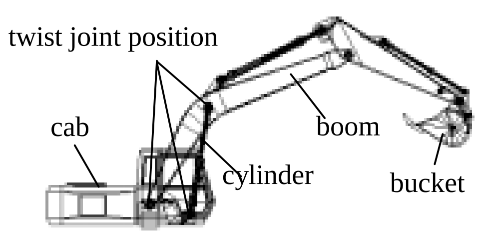

Fig.1 diagram of excavator

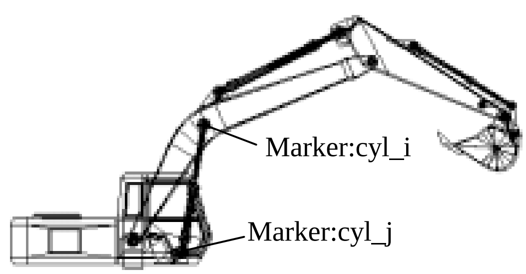

Fig.2 position of markers

Fig. 1, 2 show the diagram of hydraulic excavator. Hydraulic cylinder is the coupling component for mechanical and hydraulic systems. Driven force of hydraulic system acts on piston, and displacement, velocity and acceleration between cylinder and piston affect the changes of hydraulic pressure and flowrate. Two markers for each cylinder are create for every cylinder, marker cyl_i on boom and cyl_j on cab; they positions are on the respective revolute joint.

2.2 Hydraulic system model

ADAMS/Hydraulics package model and simulate fluid circuits and how circuits interact with mechanical models. ADAMS/Hydraulics contains most of the hydraulic components integrant to model hydraulic circuits: valves, pumps, cylinders, and so on. The components take advantage of the parameterization and function capabilities of ADAMS/View and ADAMS/Solver. The result is a powerful open environment for complete modeling of complex hydraulic-driven mechanisms and systems. Fig. 3 shows the hydraulic model of excavator in ADAMS.

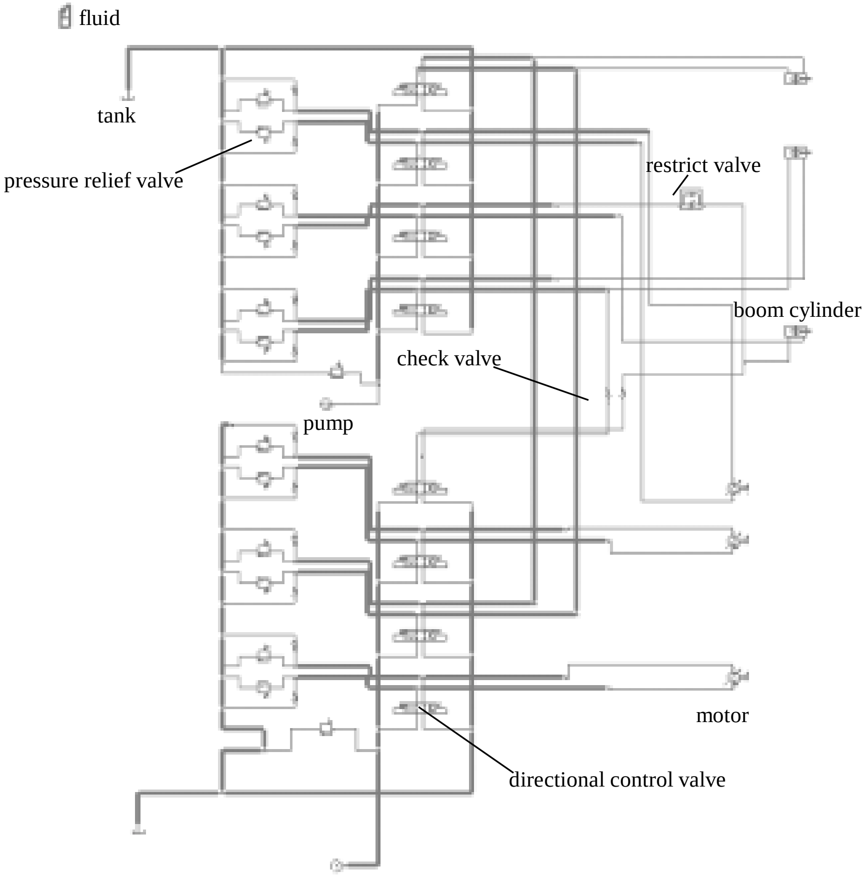

Fig.3 hydraulic circuit modeled in ADAMS

Fluid-powered circuits are connected to mechanism by directly taking the forces from hydraulic cylinders and applying these to mechanical model. There are two types executor of hydraulic force: cylinder and motor.

Cylinder force is applied to the two markers defined in section 2.1: cyl_i and cyl_j.

Motor outputs torque driving the upper portion of excavator to achieve circumgyration. The torque is defined in ADAMS/View reference as the motor output torque function. That means the “F(time,…)=” edit box in “Modify a Torque” Dialog box be given with the following characteristics: .model_name.motor.name.output_torque

2.3 Testing the vibration

Appling impact on bucket, in Fig. 4, the impulse response of boom vibration is shown. By finite element analysis of excavator working equipment, the first natural frequency is about 6.8 Hz. View from the Fig. 4, the vibration frequency is about 6~7Hz and the setting time is about 1.3 seconds. From the viewpoint of human riding comfort, it is necessary to reduce the vibration.

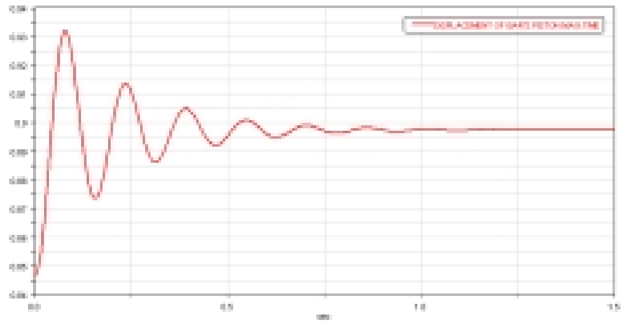

Fig.4 recorded unit impulse response of boom cylinder displacement from external force

3. Vibration control simulation

3.1 Vibration control system

The fundamental configuration of the vibration control system is shown in Fig.5 and Fig.6. The system is working as the following features:

The chambers of boom cylinder are connected by a servo valve. (the directional valve of boom is closed) The piston's displacement of boom cylinder is measured by sensor and alerted to voltage signal u_f which is sent to electric control sub-system. The signal u_f is compared with initial signal u to generate the differential voltage e .Then amplifier outputs adjust current i which drives servo valve to exports control oil q to damp the vibration.

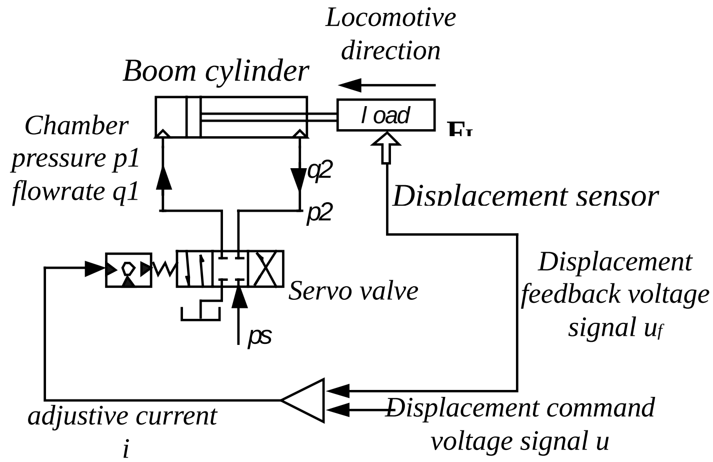

Fig.5 vibration control schematic diagram

3.2 Vibration control system model

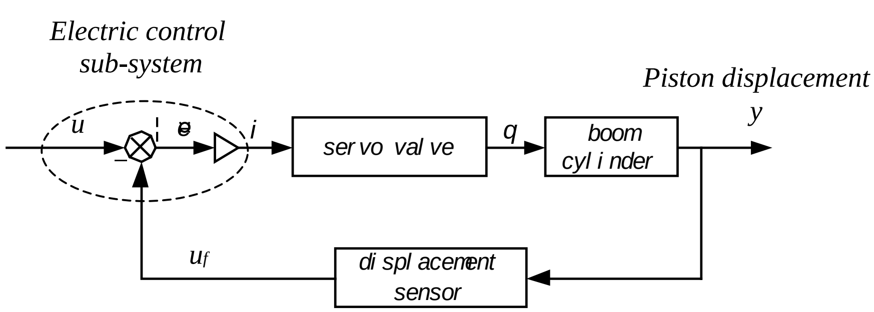

Fig.6 vibration control block diagram

The model includes hydraulic part and electric part. The displacement sensor can be replaced with "Point to Point Measure" in ADAMS because it hardly delays. The other part will be built in MATLAB environment.

3.3 Connect ADAMS/Control with MATLAB

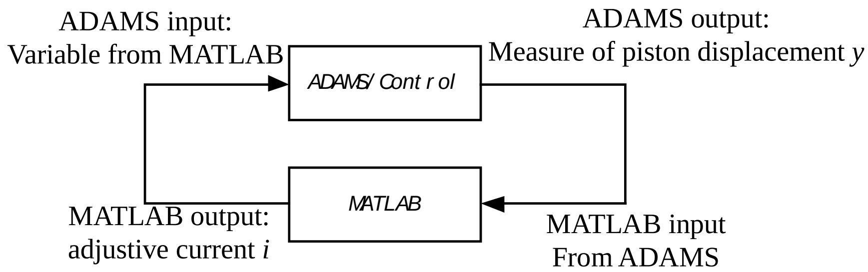

Fig.7 closed loop between ADAMS and MATLAB

ADAMS/Controls connects ADAMS model to block diagrams developed with control software package such as MATLAB. There are three-steps processes of combining controls with a mechanical system.

Step one-importing the combined model into ADAMS/Control

To start ADAMS/Control and import the combined excavator model which includes hydraulic and mechanical system.

Step two-defining the inputs and outputs in ADAMS/Control

The outputs describe the variables that go through MATLAB (the output from ADAMS/Controls is the input to MATLAB). The inputs describe the variables that come back into ADAMS (the output of MATLAB) and, therefore, complete a closed loop between ADAMS and the MATLAB as Fig. 7. In this model, ADAMS output is the measure of the boom cylinder piston displacement *y*; Input is a variable that represents spool traverse of servo valve. The input variable will be referred in control function of servo valve to output corresponding control oil. ADAMS/Controls saves the input/output information in a .m file for MATLAB and generates a command file (.cmd) and a dataset file (.amd) that are used during the simulation process.

Step three-adding controls to the ADAMS block diagram

This step uses the MATLAB to construct the controls system block diagram same as Fig.7. Firstly, running the .m file product in previous step to connect MATLAB with ADAMS/Control and import the information of inputs and outputs. Secondly, running adams_sys.m to import ADAMS block diagram

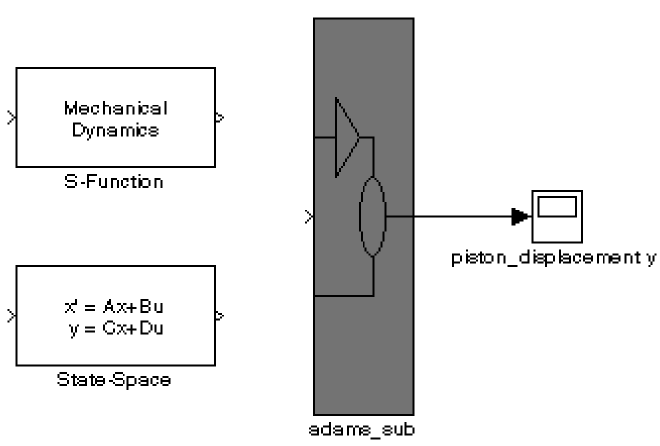

Fig.8 ADAMS block diagram

Fig. 9 shows all the elements of adams_sub block including inputs and outputs defined in ADAMS/Control.

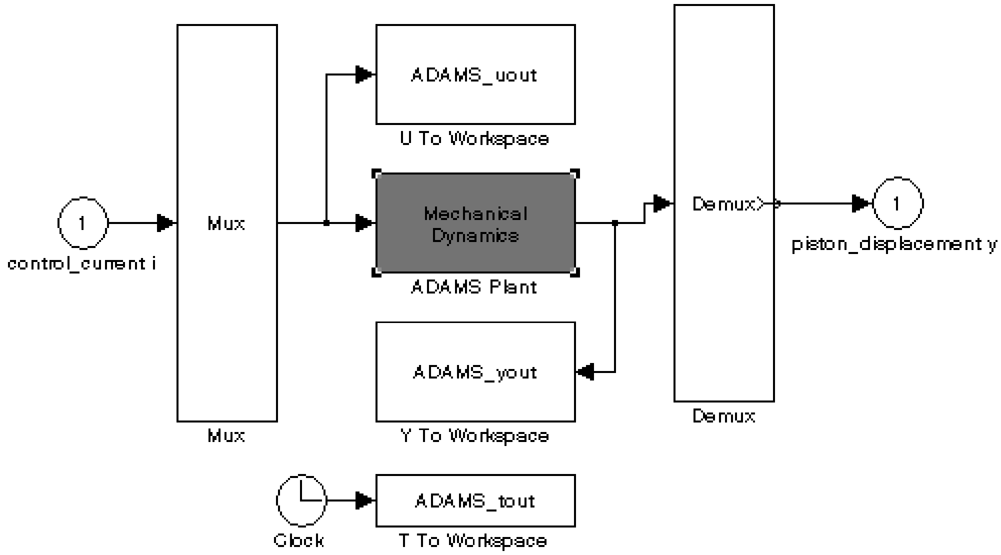

Fig.9 all the elements of adams_sub block

The completed block diagram is shown in Fig.10.

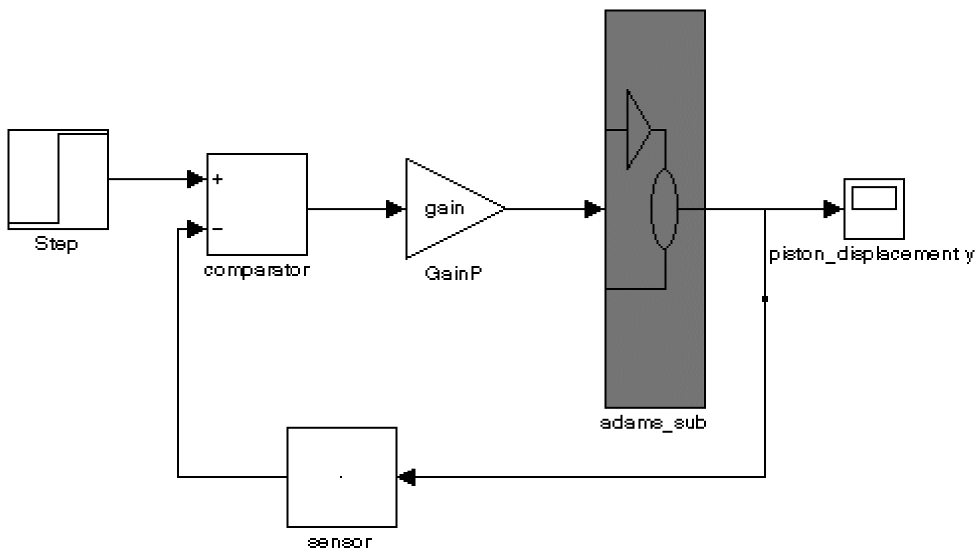

Fig.10 final block diagram in MATLAB

3.4 Simulation results

From the toolbar on the MATLAB Simulink palette, select Simulation. Then set the parameters including simulation and animation mode, enter the name of output files which ADAMS/Control saves simulation results in.

Fig.11 shows simulation results in different attitudes and working conditions. All of the setting time is shortened to less than 1/2 that of no vibration control, and the maximum response is reduced obviously. These results show good performance of the vibration control system.

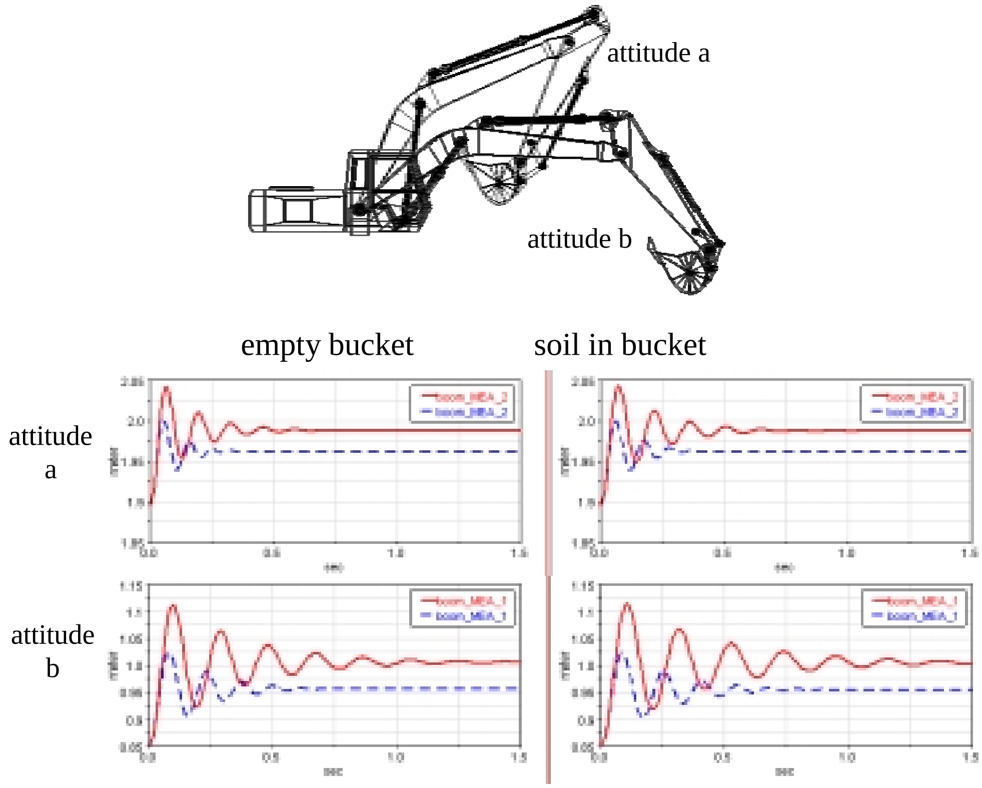

Fig.11 the different attitudes and working condition with impulse response of boom displacement accordingly

4 Conclusions

Through investigating the vibration control of the excavator boom in ADAMS environment, we conclude that the vibration is due to the oil spring of hydraulic cylinders, and the vibration control system proposed above is effective. But considering the high-cost of servo valve, a fungible control system of electro-hydraulic proportional valve is expected.

Reference

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