Simulation of the Dynamic Behavior of an Excavator due to Interacting Mechanical and Hydraulic Dynamics

Onesmus Mutuku Muvengei

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ABSTRACT

This research project primarily describes the modeling of mechanical and hydraulic dynamics of an excavating mechanism previously designed to be used with small tractors, which are fabricated in the Engineering Workshops of Jomo Kenyatta University of Agriculture and Technology. The developed models were then used to optimize the hydraulic system design, and also to simulate the open loop transient and steady state responses of the system.

In this study, bond graph method was chosen as the modeling method because, firstly, it is a domain-independent graphical method of representing the dynamics of physical systems. Therefore, systems from different engineering disciplines can be described in the same way. Secondly, the available literature shows that the method being relatively new, has not been thoroughly applied to model the dynamics of nonlinear systems such as excavators. The bond graph method was first reviewed, and then used to develop a complete dynamic model of the excavator by modeling the hydraulic actuation system and the manipulator linkage separately. The two models representing different domain dynamics were coupled to a complete model using appropriate manipulator jacobians which were treated as Modulated Transformer Elements. The bond graph method was found to reduce significantly the number of recursive computations performed on a manipulator for a mechanical dynamic model to result. This indicated, that bond graph method is more computationally efficient than the Newton-Euler method in developing dynamic models of manipulators.

The mechanical bond graph model of the manipulator was verified by comparing the joint torque expressions of a two link planar manipulator to those obtained by

using Newton-Euler and Lagrangian methods as analyzed in robotic textbooks. The expressions were found to agree indicating that the model captures the aspects of

rigid body dynamics of the manipulator. Also the bond graph model of the hydraulic system was verified by comparing the open loop state responses to those of an ODE model which has been developed in literature based on the same assumptions. The results were found to correlate very well both in the shape of the curves, magnitude and the response times, thus indicating that the developed model represents the hydraulic dynamics of a valve controlled cylinder.

Based on the model developed, actuator sizing and valve sizing methodologies were developed and used to obtain the optimal sizes of the pistons and spool valve ports respectively. It was found that using the pump with the sized flow rate capacity, the engine of the tractor is able to power the excavating mechanism in digging a sandyloom soil. The causal bond graph model of the excavator was expanded into block diagrams and simulated on MATLAB/SIMULINK to determine the transient and steady state responses of the system. From the responses obtained, the model developed was found to capture the inter-component interactions and also the interaction between the hydraulic and mechanical dynamics. Therefore it can be concluded that the model developed can be used to design control laws necessary for controlling the dynamics and motions of the excavating manipulator.