Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 176 (2017) 514 – 528

Procedia Engineering

www.elsevier.com/locate/procedia

Dynamics and Vibroacoustics of Machines (DVM2016)

Active vibration damping in hydraulic construction machinery

Addison Alexander[a,]*, Andrea Vacca[a], Davide Cristofori[b]

[a]*Purdue University, 610 Purdue Mall, West Lafayette, IN 47907, USA*
[b]*CNH Industrial, Strada di Settimo 323, San Mauro Torinese 10099, Italy*

Abstract

Hydromechanical systems are prone to significant oscillations, due to the ability of hydraulic oil to store potential energy. This is extremely important when considering mobile hydraulic machinery, especially those machines which handle large loads. Oscillations can negatively affect the stability of the payload, the comfort of the operator, and the overall safety of the system. For the particular case of earthmoving machines, several systems have been designed in order to alleviate these oscillations and increase machine operability. These systems include both passive and active designs which attempt to utilize the motion of the payload in such a way as to cancel out the effect of machine vibrations.
This paper seeks to assess the potential advantages of active oscillation control strategies with respect to current state of art passive strategies. A reference case vehicle (wheel loader) is presented and analyzed in order to determine its typical vibrational behavior. A simulation model for the reference machine is developed and used in assessing machine performance. The effectiveness of the current passive vibration damping approach with respect to reducing the vibrations perceived by the operator in the cabin, as well as those affecting the payload, is presented. Then, an active (electrohydraulic) control structure is presented using both acceleration and pressure feedback, including an adaptive controller constructed using an extremum-seeking algorithm. To quantitatively compare the relative performances of these various systems, an appropriate objective function is defined. Simulation results are presented for each of the considered control strategies, and their performances are compared. The simulation indicates a performance of active vibration control systems roughly equivalent to that of currently implemented passive control strategies. In some cases, the active control performance is actually two to three times as effective as the passive control.

Peer-review under responsibility of the organizing committee of the international conference on Dynamics and Vibroacoustics of Machines

Keywords: Vibration control; extremum seeking; hydraulics; construction machinery; electrohydraulic control; oscillation damping

* Corresponding author. Tel.: +1-765-477-1609; fax: +1-765-448-1860.
E-mail address: addisonalexander@purdue.edu

Peer-review under responsibility of the organizing committee of the international conference on Dynamics and Vibroacoustics of Machines
doi:10.1016/j.proeng.2017.02.351

1. Introduction

One of the prevalent issues related to the operation of mobile hydraulic construction machinery is the propensity of these systems to generate oscillations while traveling. Conditions such as driving on uneven surfaces introduce vibrations into the machine, which can excite certain oscillatory modes, often causing strong low-frequency motion of the system. This can have several negative effects, including decreasing implement and/or load stability, causing discomfort for the operator, and reducing the overall safety of the system. Without an adequate system for reducing machine vibrations, productivity, safety, and machine life can all suffer.

Several solutions have been proposed in the past to address this issue, with varying degrees of success. In general, these solutions fall into two different categories. The first category is that of "passive" vibration damping. These designs take advantage of the behavior of hydraulic systems, often incorporating specialized components or adding capacitive and/or resistive elements into the existing circuitry [1,2]. Passive damping is typically effective in cancelling vibrations, but only in a very limited range of operating conditions. Furthermore, by modifying the hydraulic circuit, the response dynamics of the system are often negatively impacted. Also, the additional required hydraulic elements represent an added cost for the system.

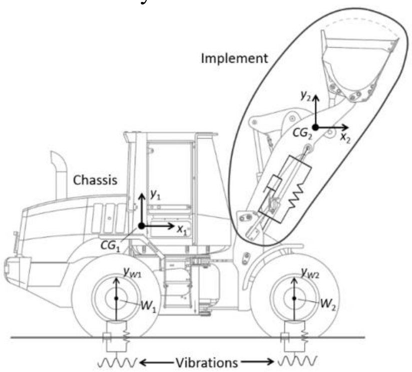

Fig. 1. Two-body system showing chassis and implement

These and other limitations of passive vibration damping systems inspired the development of "active" vibration control methods. The term active refers to the fact that these systems utilize electrohydraulic setups that actively monitor various system parameters and generate electronic signals to control the motion of the hydraulic components in such a way that the machine oscillations are cancelled out [3]. One of the main advantages of active control is that it often can be implemented in such a way that modifications to the basic layout of hydraulic system the reference machine are not required. Such control strategies have previously been applied to several prototype machines in controlled environments, including those utilizing displacement-control architectures [4,5]. This work, on the other hand, focuses on a more conventional hydraulic architecture for controlling actuators through hydraulic control valves. The schemes presented in this paper use either machine acceleration or hydraulic pressure to synthesize the control signal.

The active ride control method put forth in this work utilizes a simple, non-model-based controller to damp the machine vibrations. This simple control structure has several benefits, in that it can be transferrable from one system to another and the theory behind it is well understood. However, this also means that the controller relies heavily on an online optimization method in order to work properly for any given system. To verify the feasibility of the the proposed controller, and to gain an understanding of the system behavior, a simulation model was created.

A basic schematic of this system model is shown in Fig. 1. It includes considerations for rigid body motion and hydraulic system dynamics, as well as a simple tire deflection model. Oscillations are introduced into the system through vibrations represented as vertical motion of the tire/road interface. The tires themselves are modeled as a spring-damper connection between the road surface and the axle of the machine.

Using the simulation model, the effectiveness of the current passive vibration damping approach is analyzed. The existing passive system is based on the addition of a capacitive element (accumulator) and a resistive element (4/4