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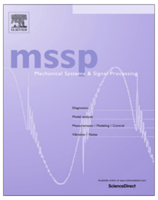

Self-tuning pressure-feedback control by pole placement for vibration reduction of excavator with independent metering fluid power system

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ABSTRACT

Independent metering control systems are promising fluid power technologies compared with traditional valve controlled systems. By breaking the mechanical coupling between the inlet and outlet, the meter-out valve can open as large as possible to reduce energy consumptions. However, the lack of damping in outlet causes stronger vibrations. To address the problem, the paper designs a hybrid control method combining dynamic pressure-feedback and active damping control. The innovation resides in the optimization of damping by introducing pressure feedback to make trade-offs between high stability and fast response. To achieve this goal, the dynamic response pertaining to the control parameters consisting of feedback gain and cut-off frequency, are analyzed via pole-zero locations. Accordingly, these parameters are tuned online in terms of guaranteed dominant pole placement such that the optimal damping can be accurately captured under a considerable variation of operating conditions. The experiment is deployed in a mini-excavator. The results pertaining to different control parameters confirm the theoretical expectations via pole-zero locations. By using proposed self-tuning controller, the vibrations are almost eliminated after only one overshoot for different operation conditions. The overshoots are also reduced with less decrease of the response time. In addition, the energy-saving capability of independent metering system is still not affected by the improvement of controllability.

1. Introduction

1.1. Motivation

Reduction of the vibration is a serious concern for many flexible manipulators arms ranging from mobile machine (e.g., excavator, crane, forester machinery) to industrial crane [1,2]. For mobile machine, large vibrations will decrease machine life and control performance, even influence the operator's comfort and safety levels.

Mobile machines are always driven by hydraulic systems, because of their high power-to-weight ratio compared with electric drives [3–5]. In traditional systems, each actuator is controlled by a proportional directional valve, which the two

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Nomenclature

A_a	head side area of cylinder (m^2)
A_b	rod side area of cylinder (m^2)
A_v	orifice area of proportional valve (m^2)
B_p	coefficient of viscous friction
C_q	flow coefficient
F_l	load force (N)
K_{ca}	flow-pressure gain of meter-in valve
K_{cb}	flow-pressure gain of meter-out valve
K_{com}	gain of dynamic pressure feedback control
K_d	differentiation coefficient
K_i	integration coefficient
K_p	proportion coefficient
m_t	equivalent load mass (kg)
p_a	pressure in head side chamber (Pa)
p_{a1}	pressure in head side chamber of boom cylinder (Pa)
p_{a2}	pressure in head side chamber of arm cylinder (Pa)
p_b	pressure in rod side chamber (Pa)
p_{b1}	pressure in rod side chamber of boom cylinder (Pa)
p_{b2}	pressure in rod side chamber of arm cylinder (Pa)
$p_{b,e}$	difference of reference pressure and actual pressure (Pa)
$p_{b,ref}$	reference pressure in rod side chamber (Pa)
p_{Ls}	load pressure (Pa)
p_r	drain pressure (Pa)
p_s	pump pressure (Pa)
Δp_1	pressure difference of valve 1 (Pa)
Δp_2	pressure difference of valve 2 (Pa)
Q_{actual}	calculated flow (m^3/s)
Q_a	flow of head side chamber (m^3/s)
Q_b	flow of rod side chamber (m^3/s)
Q_{diff}	equivalent flow in differential mode (m^3/s)
Q_e	flow difference between reference flow and calculated flow (m^3/s)
Q_{ref}	reference flow (m^3/s)
Q_s	pump flow (m^3/s)
$Q_{s,ref}$	reference flow for pump (m^3/s)
u_1	control voltage of valve 1 (v)
u_2	control voltage of valve 2 (v)
u_{com}	compensation voltage from dynamic pressure feedback control (v)
u_p	control voltage of pump (v)
V_a	volume of head side chamber of boom cylinder (m^3)
V_b	volume of rod side chamber of boom cylinder (m^3)
V_{diff}	equivalent fluid volume in differential mode (m^3)
v_c	cylinder velocity (m/s)
V_{dead}	volume of dead chamber of cylinder (m^2)
v_{ref}	reference velocity of cylinder (m/s)
v_1	velocity of boom cylinder m/s)
$v_{1,ref}$	reference velocity of boom cylinder (m/s)
v_2	velocity of arm cylinder (m/s)
$v_{2,ref}$	reference velocity of boom cylinder (m/s)
x_c	cylinder piston displacement (m)
$x_{c,max}$	cylinder piston stroke (m)
x_0	initial cylinder piston displacement (m)
ξ_h	damping
β_e	equivalent modulus of elasticity
θ	poles angle down from real axis (deg)
ω_c	cut-off frequency of dynamic pressure feedback control (Hz)
ω_h	hydraulic resonance frequency of normal mode (Hz)
ω_{diff}	hydraulic resonance frequency of differential mode (Hz)
ρ	oil density (kg/m^3)
σ	mode switch signal
κ	area ratio of rod side and head side