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On Path Oscillations Analysis of Mechanical Multi-body and Hydrostatical Driving Units Coupled System

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Abstract

This research deals with the path dynamics of the multi-body systems embedding hydrostatically actuating units. The main purpose of this analysis consists by an optimal dynamic response of the mechanic and hydraulic coupled ensemble, taking into account the characteristic requirements for the final path of the working tool. Theoretical background contains elements both for the multi-body dynamics of mechanical parts, and for the hydraulic driving systems. The forward analysis in terms of command – action connection, and the reverse analysis in terms of system response evaluation and actuating system control frame the main research problem of this study. A computational application developed within Matlab-SimScape software was provided, and a comparative analysis between simulation data and experimental test results was presented. A practical example was developed based on the excavating equipment with a single bucket.

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Keywords: multi-body dynamics; hydrostatic driving system; optimal dynamic response; vibration; control.

1. Introduction

There are two aspects for fulfilling proposed goals relating to control trajectory of the bucket: describing forward and inverse kinematics of the excavator – most commonly considering three degree of freedom according with the boom, arm and bucket respectively – and studying dynamics behaviour of the main parts subjected velocities, forces

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or torques applied. The most of models contained in available literature take into account by the singular actions (only kinematics aspects of the working body represented by boom, arm, and bucket; only mechanical dynamics of the excavator body; only dynamical interacting of the hydraulic drive system) and fewer papers consider the complex actions such as interaction between mechanical and hydraulic dynamics of excavator.

The causes which vibrations occurring on the excavator body are multiple: nonlinearities of the hydraulic system dynamics due to the oil spring into hydraulic cylinders, due to the friction in joints, due to the characteristics of the command devices or improper design of the hydraulically actuated mechanisms (i.e. the piston area of the hydraulic cylinder); the masses and inertias of the main parts of excavator and of the mechanical links; the variation of the bucket forces developed into digging process (because of random properties of the soils) which is characterized by a high degree of nonlinearity and uncertainty.

The minimizing of the effects due the transient stage when the operator maneuvers the excavator represents a continuing concern of specialists who develop new techniques and methods for achieving of this desideratum [1, 2, 3]. Several researchers [2, 4] proposed methods to minimize the vibrations on the driving joint forces and torques of boom, arm and bucket using systems (with active damper or impedance control of hydraulic cylinder), which compensates the disturbances forces generated by these joints, implemented in a bucket trajectory control system with influence on reducing the oscillation of the working body of excavator. Many researchers bring contributions to obtaining of the optimal trajectory of the bucket taking under consideration many criteria, such as: filling the bucket and minimal excavating force [5]; minimal time or minimal torque execution [6]; optimal mechanism design of working device [7]; minimal vibrations developed into excavator mechanism during of digging operation [2]; type of control system (electronic, electric, hydraulic etc.) [1, 4].

The authors propose a complete multi-body model embedding hydrostatic driving unit, and provide a computational analysis based on data according with real excavating equipment – regular type equipment modified for experimental research purposes.

Nomenclature

α_{01}, α_{12}, α_{23} functional (operational) angles
L_{01}, L_{02}, L_{03} hydraulic actuators length
δ the embankment angle in respect with horizontal reference
W_S the internal command reference
V_R proportional factor of the pump regulator
T_V time constant of servo-valve
V_Q servo-valve flow gain
A_S available area of servo-actuator
V_{Q1} flow gain of the hydrostatic pump unit
T_H time constant of the hydrostatic unit
V_H hydrostatic unit gain
T_M time constant of the mechanical parts
V_M gain of the mechanical parts
W the input signal (external reference in terms of hydraulic actuator displacement)
x the output signal (rod displacement)
y_S the intermediate output (at servo-actuator rod)
ω_S natural frequency of the servo-actuator
A available area of the hydraulic actuator
K_V loss coefficient within the hydraulic actuator (in respect with output velocity)
D_S regulator damping coefficient
K_I, K_P, K_D controller gains for integrator, proportional and derivative components respectively
F_L external load of the hydrostatic driving system
ω_H natural frequency of the hydrostatic unit
D_H damping coefficient of the hydrostatic unit

2. Theoretical background

Three degrees of freedom model for this serial multi-body approach was proposed. Based on the schematic diagram depicted in Fig. 1(a) according with a regular excavating equipment configuration, and used the inverse kinematical method, it was evaluated the analytical expressions of the angular displacements for each driving joint in respect with desired embankment characteristics.

The snapshots of the three essential positions of the working tool (bucket), shown in Fig. 1(b), was presented in order to justify the hypothesis that the equipment kinematics will be evaluated based on certain position of the