Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Control Engineering Practice 14 (2006) 137–147
CONTROL ENGINEERING PRACTICE
www.elsevier.com/locate/conengprac

An experimental study on the optimization of controller gains for an electro-hydraulic servo system using evolution strategies

Min Young Kim*, Chung-Oh Lee

Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305701, Korea

Received 11 October 2003; accepted 20 January 2005
Available online 12 March 2005

Abstract

This paper deals with an experimental optimization problem of the controller gains for an electro-hydraulic position control system through evolution strategies (ESs)-based method. The optimal controller gains for the control system are obtained by maximizing fitness function designed specially to evaluate the system performance. In this paper, for an electro-hydraulic position control system which would represent a hydraulic mill stand for the roll-gap control in plate hot-rollings, the time delay controller (TDC) is designed, and three control parameters of this controller are directly optimized through a series of experiments using this method. It is shown that the near-optimal value of the controller gains is obtained in about 5th generation, which corresponds to approximately 150 experiments. The optimal controller gains are experimentally confirmed by inspecting the fitness function topologies that represent system performance in the gain spaces. It is found that there are some local optimums on a fitness function topology so that the optimization of the three control parameters of a TDC by manual tuning could be a task of great difficulty. The optimized results via the ES coincide with the maximum peak point in topologies. It is also shown that the proposed method is an efficient scheme giving economy of time and labor in optimizing the controller gains of fluid power systems experimentally.

Keywords: Controller gain optimization; Evolution strategies; Time delay control; Automatic controller gain search; Electro-hydraulic servo system

1. Introduction

Recently, the research on the optimization and adaptation of controller gains or parameters for improving the system performance in hydraulic and pneumatic servo systems has been a field of increasing interest (Fleming & Purshouse, 2002; Klein, 1992; Jeon, Lee, & Hong, 1998; Hyun & Lee, 1998; Choi, Lee, & Cho, 2000). In general, when control engineers design a controller for hydraulic or pneumatic servo systems, it is very difficult to determine theoretically its control gains to exhibit the best performance of the systems, because the accurate modeling for these systems is hard due to highly nonlinear characteristics of the fluid power systems. To be more specific, the hydraulic and pneumatic servo systems already have a relatively higher degree of nonlinearity than other mechatronic systems like DC or AC servo systems. It result from various factors (Merrit, 1976; Watton, 1989): the pressure-flow characteristics of valve, the saturation of valve and cylinder, the leakage flow characteristics of valve and cylinder with variation of supply pressure, the friction characteristic in cylinder, the variation of viscosity and compressibility of working fluid with the temperature, the flow characteristic due to the shape of pipeline, and most importantly, the variation of the system gains with the supply pressure and the load pressure. Therefore, when these fluid power systems are controlled, the controller gains are adjusted on the foundation of expert's intuitive knowledge about the system and the

*Corresponding author. Tel.: +82 42 869 3253; fax: +82 42 869 3210.
E-mail address: mykim@lca.kaist.ac.kr (M.Y. Kim).

0967-0661/$ - see front matter
doi:10.1016/j.conengprac.2005.01.010

Nomenclature

A	individual vector, Eq. (2)
E	control gain of TDC related to the known range of the system inertia
e	position error of X with respect to X_d, $e \equiv X_d - X$
i_1	control current signal for servo valve 1
i_2	control current signal for servo valve 2
L	sampling time for the control system
n	number of objective variables
n_σ	number of strategic variables
P_s	supply pressure of fluid power system
s	variable of Laplace transform
U	control input for the control system
X	position of the roll-gap control cylinder
X_d	desired position of the roll-gap control cylinder
Z	objective variables vector, $\mathbf{Z} = \{Z_1, Z_2, Z_3\} = \{E, \omega_n, \zeta\}$

Greek letters

λ	number of offsprings in each generation
μ	number of parents in each generation
σ_E	strategic parameter for E gain
σ_ω	strategic parameter for ω_n gain
σ_ζ	strategic parameter for ζ gain
$\sigma_i(0)$	initial value of strategic parameter, where $i \in \{1, 2, 3\}$
$\boldsymbol{\sigma}$	strategic parameter vector, $\boldsymbol{\sigma} = \{\sigma_1, \sigma_2, \sigma_3\} = \{\sigma_E, \sigma_\omega, \sigma_\zeta\}$
ω_n	control gain of TDC to denote the natural frequency of the closed-loop system
ζ	control gain of TDC to denote the damping ratio of the closed-loop system

tuning experience of the controller gains in general. It needs very excessive experiments through trial and error. But though some controller gains are obtained, it is hard to say that the results are the best gain set at a given situation. For the automatic adjustment of the controller gains in fluid power systems, the research to application of a fuzzy gain adapter (FGA) has been performed (Jeon, 1997; Klein, 1992). In this case, the knowledge base is needed for transplantation of the expert knowledge to the systems, and some general rules to variation of the system response due to variation of the controller gains are demanded for the construction of this knowledge base. Therefore, much expert's experiences and many experiments are necessary for the implementation of this algorithm.

In this study, *evolution strategies* (ESs) is proposed as a method of the automatic optimization of the controller gains in a electro-hydraulic system. ES is one of the evolutionary algorithms based on the natural genetics and the survival of the fittest (Rechenberg, 1973; Schwefel, 1981; Back & Schwefel, 1994, 1996). When an appropriate fitness function representing potential solutions is given as survivability of candidates, the tuning problem of controller gains can be considered as an optimization problem, so that an optimal controller gain set is searched in the region of gain spaces specified by operator. A major advantage is that much experience on the gain-tuning for the control system is not required, and the least information for the system is just required. Especially, in cases that a real experimental system is directly used for evaluating candidates, ESs are more suitable than other evolution algorithms due to its own characteristic called self-adaptation.

In this study, a time delay controller (TDC) is designed as a controller for position control of an electro-hydraulic servo system. The controller designed to have 2nd order error dynamics has three controller gains implicitly. By using an ES as optimization algorithms, the optimal controller gain set in the specified gain spaces is determined through online experiments. For the verification of the obtained results, the fitness function topologies in the gain spaces experimentally are made out, and analyzed. Finally, the experimental results searched through ESs are shown to coincide with the optimal peak point that has best fitness value on the specified gain spaces.

2. Hydraulic servo system

2.1. Electro-hydraulic position control system

Fig. 1 is the schematic diagram of the electro-hydraulic position control system used in this study. This system is a test rig for the roll-gap control of hydraulic mill stand, which was made for the improvement of thickness control performance in plate hot-rolling processes (Gizburg, 1984; Lee, Lim, & Park, 1997). The rig simulates a roll-gap control system composed of a hydraulic mill stand in a number of automatic gauge control systems for hot rolling processes. The system consists of *structure spring* to represent a modulus of mill stand, *material spring* to represent a modulus of rolled strip, *roll-gap control cylinder* to control a deformation of material spring, and *disturbance cylinder* to give the control system a disturbance. The force applied to roll-gap cylinder is measured through *Load cell*, the deformation of