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An experimental study of the dual-loop control of electro-hydraulic load simulator (EHLS)

Wang Chengwen, Jiao Zongxia *, Wu Shuai, Shang Yaoxing

Science and Technology on Aircraft Control Laboratory, School of Automation Science and Electrical Engineering, Beihang University, Beijing 100191, China

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Surplus torque

Abstract This paper investigates motion coupling disturbance (the so called surplus torque) in the hardware-in-the-loop (HIL) experiments. The "velocity synchronization scheme" was proposed by Jiao for an electro-hydraulic load simulator (EHLS) in 2004. In some situations, however, the scheme is limited in the implementation for certain reasons, as is the case when the actuator's valve signal is not available or it is seriously polluted by noise. To solve these problems, a "dual-loop scheme" is developed for EHLS. The dual-loop scheme is a combination of a torque loop and a position synchronization loop. The role of the position synchronization loop is to decouple the motion disturbance caused by the actuator system. To verify the feasibility and effectiveness of the proposed scheme, extensive simulations are performed using AMESim. Then, the performance of the developed method is validated by experiments.

1. Introduction

Load simulator (LS) is a crucial device in hardware-in-the-loop (HIL) experiments, and it is widely used in aerospace engineering. Its main function is to produce a load torque/force acting on an actuator system, so that the control performance and reliability of the whole actuator system can be tested in a laboratory. The designer of the actuator system, by virtual of the LS, can foresee and detect potential problems related to the mechanics and flight control system.[1]

According to its energy source type, the LS can be classified into three types: electro-hydraulic load simulator (EHLS), electric load simulator (ELS) and pneumatic load simulator (PLS). Compared with ELS and PLS, EHLS has some advantages, such as durability, high power to weight ratio and reliability.[2–4] In view of these, EHLS has found wide application in aircraft and missile industries,[5,6] automotive industry,[7] robotics and the fault tolerant field.[8] Different from the familiar loading system, EHLS needs to track the torque/force reference under an actuator's active motion disturbance. Because of the direct connection between the actuator and EHLS, the torque output of the EHLS is seriously influenced by the actuator's motion. Liu named the disturbance "surplus torque/force".[9] In broad terms, the performance of an LS is largely determined by the level of surplus torque suppression. How to eliminate the actuator's motion disturbance has been of great interest for both academia and industries. In this paper, these studies are divided into four types, i.e.,

* Corresponding author. Tel.: +86 10 82338938.
E-mail addresses: cwwang@yeah.net (C. Wang), zxjiao@buaa.edu.cn (Z. Jiao).

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(A) parameter optimization method, (B) feed-forward compensation method, (C) robust control method, and (D) velocity synchronization method.

The basic idea of the parameter optimization method is to reduce the intensity of an actuator's disturbance through the optimization of some parameters, such as the leakage coefficient of the loading system,[5,10] the connecting stiffness between the actuator and the loading system,[11,12] etc. The advantage of these methods is easy implementation, but it is always accompanied by some "side effects". The feed-forward compensation method is based on the linear theory, and the most usual feed-forward signal is the actuator's velocity.[5,13] For the robust control methods of LS, certain control algorithms with robust property are performed for it. So far the H_∞ mixed sensitivity theory,[14] quantitative feedback technology (QFT) and disturbance observer technology[15,16] have been investigated for EHLS. In addition, the neural networks[17] and self-tuning fuzzy PID[18] have been applied to EHLS. The velocity synchronization method employs a control scheme proposed by Jiao et al. in 2004.[19] For this method, the actuator's valve input is used and superimposed on the control output of the torque controller. This method has been applied in several HIL experiments successfully, and certain effectiveness is acquired. However, it has encountered some problems during the implementation in a number of situations (see Section 3).

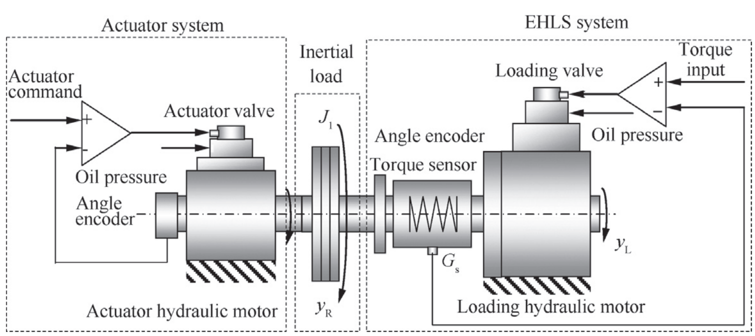
This paper tries to solve the problem of actuator's motion disturbance by a simple engineering way. The main contribution of this work is that a dual loop control scheme is proposed for EHLS. The rest of the paper is organized as follows. Section 2 establishes the mathematical model of EHLS. Then, the surplus torque problem is analyzed based on the mathematical model. In Section 3, the problem encountered during the implementation of the velocity synchronization method in practice in analyzed. Section 4 presents the results of simulations and experiments. Finally, conclusions are drawn in Section 5.

2. Description of EHLS

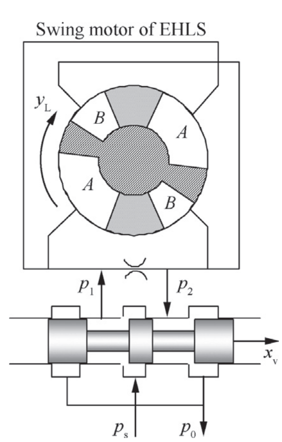
2.1. System structure

In general, an HIL experiment is composed of two servo systems: the actuator system and the loading system. The schematic diagram and oil line principle are described by Fig. 1. In the figure, J_L is the rotary inertia of the loading shaft, G_s is the stiffness of the torque sensor, y_L and y_R are the angular displacement of the loading and actuator system, P_1 and P_2 are the pressure inside each of the two chambers, x_v is the spool displacement of the loading valve, P_s and P_0 are the supply and return pressure.

In Fig. 1(a), the left part represents the position actuator system which consists of a servo valve, a hydraulic swing motor and an angular encoder. The actuator angle is feedback into the actuator controller to achieve closed loop angle control. The right part is the loading system which is composed of a valve controlled hydraulic swing motor, a torque sensor,



(a) Schematic presentation of the EHLS



(b) Oil line principle

Fig. 1 Schematic and oil line principle of EHLS.