# An Experimental Study of Delayed Positive Feedback Control for a Flexible Plate

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(Received 27 February 2012; Revised 25 June 2012; Accepted 11 September 2012)

Active vibration control generally produces negative feedback, while positive feedback may cause degradation of control efficiency and even make a control system unstable. The current study indicates that positive feedback can also benefit the control if appropriate time delay is intentionally introduced into the control system. This is the so-called delayed positive feedback control technique. So far, most of the work on this technique is theoretical, and few are experimental in nature. This paper presents a theoretical and experimental study of the delayed positive feedback control technique using a flexible plate as the research object. The positive feedback weighting coefficient is designed using the optimal control method. The available time delay is determined by analyzing the maximal real part of characteristic roots of the system. A DSP-based experiment system and experimental data processing are described in detail. The simulation and experimental results indicate that the delayed positive feedback control may effectively reduce the plate vibration if the time delay is appropriately selected.

## 1. INTRODUCTION

In recent decades, delayed system dynamics have been attracting more and more researchers' attention in mathematics, mechanics, structure and automation, etc., and many advancements have been achieved in stability, nonlinearity, and delay compensation.[1] Time delay exists inevitably in active control systems and may affect the system property and cause complicated dynamic behaviors. The research on time delay is of important theoretical significance and practical value.

Generally speaking, studies of time delay in active structural control can be divided into two classes: elimination and utilization technologies. At first, time delay was regarded as a negative factor; it may result in non-synchronization of control forces, which may cause actuators to apply energy to the control system when energy is actually not needed, induce degradation of control efficiency, and even make the system unstable. Therefore, it needs to be compensated for in control design in order to eliminate its negative effect on control efficiency. Thus far, some methods have been proposed to handle time delay problems, such as the expansion of the Taylor series,[2] the technique of phase shift,[3] and the advance estimation of state variables.[4] Due to the inherent restrictions with each of the three methods, they can only deal effectively with a small time delay in a control system, but awkwardly with a large one. Cai and Huang have recently proposed two new time-delay controllers: one is in continuous form and the other is in discrete form.[5,6] These delay controllers are designed directly from a time-delay differential equation without any hypothesis, suitable for both small and large time delays. Cai and Chen verified these two methods through experiments on several flexible structures.[7,8] The methods mentioned above to eliminate the negative effect of time delay are the so-called time-delay elimination technology or time-delay compensation technology. Its main function is to eliminate or weaken the negative effect of time delay on control efficiency. On the other hand, recent studies have shown that voluntary introduction of delay into a control system can also benefit the control. Utilizing a time delay to create a delayed feedback control loop can improve the control performance and system stability. For example, in nonlinear dynamics, there is a remarkable achievement when using a time delay to control chaos motion.[9,10] In structural control, Hosek and Olgac developed a time-delay resonator that may be used for vibration control of structures.[11] In robotics, Cai and Lim designed a time-delay controller for a flexible manipulator, and their results show that delayed feedback control design may possibly achieve much better control efficiency than the control design without a time delay.[12] In the control system of pipeline transport, a time delay may be utilized to enhance the steady critical speed of flowing liquid.[13] Time delay may be also used to improve system stability.[14,15] Those methods described above, involving the active utilization of a time delay, are the so-called time-delay utilization technology, which assumes time delay as a design parameter to obtain good control performance.

Time delay in control systems may induce complicated dynamic behaviors. Even for a very simple time-delay dynamic system, such as the first-order Ikeda (autonomous) system, bifurcation and chaos may occur. It is well known that for active structural control, the classical control algorithm adopts the negative feedback technique. Essentially, negative feedback adds active stiffness and damping to the structures, and the active damping term plays the dominant role in reducing the vibration amplitude of the structures. Conversely, positive feedback may only enlarge system responses and deteriorate system stability, which is the case when a time delay is not involved in the control path. If a time delay is appropriately introduced into the feedback control loop, positive feedback is not necessarily bad for control efficiency; on the contrary, it may lead to better control results. Recently, delayed positive feedback control has been captured many researchers' attention, and some studies have been undertaken. For example,