Improving Pushbelt Continuously Variable Transmission Efficiency via Extremum Seeking Control

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1 Background

The infinite number of transmission ratios in a continuously variable transmission (CVT) provides more freedom to match the engine operating conditions to the variable driving conditions in comparison with power transmission devices with a fixed number of transmission ratios. This improves the fuel consumption of the vehicle. The transmission ratio is realized by the variator, a friction drive, see Fig. 1, which consists of a metal V-belt that is clamped between two pairs of conical sheaves. The research is concerned with the variator control design, where the objective is to further improve the variator efficiency, while the variator functionality is preserved.

![Fig. 1: Pushbelt CVT variator (Left: Test rig; Right: Illustration).](image)

2 Variator Control Design

2.1 Actuators and Sensors

In production CVTs, the clamping forces $F_p$ and $F_s$ (Fig. 1) are applied by the hydraulic actuation system, which includes two servo valves. The manipulated variables are the servo valve currents $I_p$ and $I_s$. The measured variables are the secondary clamping force $F_s$ and the angular velocities $\omega_p$ and $\omega_s$ (Fig. 1). Furthermore, $T_p$ and $T_s$ (Fig. 1) denote the torques.

2.2 Control Objectives

The control objectives are: 1) track a prescribed speed ratio reference $r_{s,ref} = \omega_s / \omega_p$ and 2) optimize the variator efficiency $\eta = \omega_s / \omega_p$. Clearly, the variator efficiency is a performance variable that is not measured. Hence, a measured variable is required that indicates performance.

3 Experimental Results

In the experiments, the primary moveable conical sheave is fixed. This isolates the problem of optimizing the variator efficiency and neglects the problem of tracking a prescribed speed ratio reference. In Fig. 2 (Left), open loop experiments are shown in which $F_s$ decreases. Conclusions are: 1) a global maximum exists in the $F_s$-$\eta$ map, 2) a global maximum in the $F_s$-$r_s$ map, and 3) the extrema in 1) and 2) occur for nearly the same value of $F_s$. Hence, the speed ratio $r_s$ indicates performance.

![Fig. 2: Experiments (Left: Open loop; Right: Closed loop) (solid: Measurement; dashed: Extremum in $F_s$-$r_s$ map; dashed-dotted: Conventional variator control design).](image)

The extremum in the $F_s$-$r_s$ map is found by means of extremum seeking control (ESC) [1] in a stable way. In Fig. 2 (Right), closed loop experiments are shown in which $F_s$ decreases. The ESC algorithm converges towards a small neighborhood of the extremum in the $F_s$-$r_s$ map and outperforms a conventional variator control design.

References