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A two-level Iterative Learning Control scheme for the engagement of wet clutches

B. Depraetere [a,*], G. Pinte [b], W. Symens [b], J. Swevers [a]

[a] Department of Mechanical Engineering, Celestijnenlaan 300 B, B-3001 Leuven, Belgium
[b] FMTC, Celestijnenlaan 300 D, B-3001 Leuven, Belgium

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ABSTRACT

This paper discusses the application of Iterative Learning Control (ILC) algorithms for the engagement of wet clutches. A two-level control scheme is presented, consisting of a high level ILC-type algorithm which iteratively updates parameterized reference trajectories which are tracked by the low level tracking control. At this low level, two standard ILC controllers are used to first track a pressure reference in the filling phase and afterwards a slip reference in the slip phase of the clutch engagement. The performance and robustness of the presented approach are validated on an experimental test setup. It is shown that both levels are crucial to achieve good engagement quality during normal machine operation. Through the use of this ILC control scheme, it is possible to avoid time-consuming and cumbersome experimental (re)calibrations, which are nowadays used to achieve and maintain good performance despite the complex and time-varying dynamics of wet clutches.

1. Introduction

Wet clutches are mechanical devices used to transmit torque from their input shaft to their output shaft by means of friction. They are used in various types of automatic transmissions to selectively engage gear elements. By disengaging one clutch and engaging another, different transmission ratios can be realized. Wet clutches are also used for off-road vehicles and agricultural machines where high torques are transmitted. These vehicles typically operate under varying environmental conditions and the clutches wear out over time [1]. In addition to this time-varying behavior, the dynamics of clutches are highly non-linear [2]. Operators however always expect a fast and smooth response without drivetrain jerking, so without oscillations induced due to a poor engagement. These expectations combined with the varying and non-linear clutch dynamics make wet clutch control a challenging industrial problem [3]. Current industrial controllers use parameterized feedforward signals that are experimentally calibrated. To cope with the varying dynamics the signal parameters are regularly recalibrated during machine servicing. In an attempt to avoid this downtime, various patents have been claimed that describe empirical rules for adjusting the signal parameters during normal machine operation, based on observations of past engagements [4–6]. In this paper, a control scheme based on Iterative Learning Control (ILC [7,8]) is presented as an alternative, efficient strategy to learn and adapt the control signals during normal machine operation without the need for recalibrations.

A schematic cross-section of a wet clutch is shown in Fig. 1. Its input shaft is connected to a hollow cylinder with internal grooves, called the drum. A first set of friction plates (clutch plates) with external toothing can slide in those grooves, while a second set of friction plates (clutch discs) with internal toothing can slide over a grooved bus connected to the output shaft. Torque is transferred between the shafts by pressing both sets together with a hydraulic piston, realized by sending a control signal to the servovalve in the hydraulic line to the clutch. When this is done, the clutch chamber first fills up with oil and the pressure builds up until it is high enough to compress the return spring and move the piston towards the friction plates. This is called the filling phase, and it ends once the piston advances far enough and presses the plates together such that torque transfer commences. At this moment the slip phase begins and the system dynamics change considerably, yielding strongly non-linear system behavior. The difference in rotation speeds between the in- and output shafts, denoted the slip, then decreases until both shafts rotate synchronously. A good engagement is obtained when torque transfer starts as soon as possible without introducing torque peaks, which can be realized by a short filling phase and a smooth transition into the slip phase. This control problem is further complicated by the fact that the piston position is generally not measured on industrial machines. Only pressure sensors measuring the pressure in the line to the clutch and encoders measuring rotational speeds of the in- and output shafts of the clutch are available.

Several authors have derived full physical models for wet clutches [2,9–14]. These have been applied to the design of feedback controllers in [2,10] and feedforward controllers in [11,12]. This requires a large effort to get accurate models, typically

* Corresponding author. Tel.: +32 16 322539.
E-mail address: bruno.depraetere@mech.kuleuven.be (B. Depraetere).

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