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Novel clamping force control for electric parking brake systems

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ABSTRACT

In this paper, we present a novel control method with clamping force estimation for an electric parking brake system. This simple control structure can be implemented at low cost as it does not require a clamping force sensor. The characteristic curve is conventionally used to estimate the clamping force through the angular displacement of the DC motor; however, this can result in error because of the dependence of the curve on the brake clearance between the brake pads and brake disk at release. We solve this problem by approximating the initial contact point using the angular velocity of the motor. We then propose a novel on–off control method to avoid excessive clamping forces by predicting the additional angular displacement after power-off caused by the inertia effect. Finally, we experimentally validate our proposed control method.

1. Introduction

Brake-by-wire systems have manufacturing advantages and are therefore installed in many vehicles [1]. An electric parking brake (EPB) system is a type of electromechanical brake-by-wire system that replaces the conventional lever parking system by generating a clamping force for parking using electric motor torque [2]. At the push of a button, a driver can easily apply or release the parking brake; this enables elderly or disabled persons to easily apply a full braking load on highly inclined surfaces [3]. The EPB system operates quickly and over a wide force range through the use of electrical components. It supports dynamic braking, anti-lock braking, key-out application, hill hold, and drive-away release, in addition to its conventional parking brake function [1,4,5].

The general control architecture used for the brake-by-wire system is a force control loop with a force sensor that is used to measure the clamping force [6–8]. Recently, due to cost issues and implementation difficulties, research has been conducted to determine if the force sensor can be eliminated from the system and if the clamping force can be estimated based on the sensory outputs of an alternative system. These outputs include the angular displacement of the motor [9–12] or the combination of motor voltage, current, and speed measurements [13]. The motor position can be obtained from a resolver or an encoder. A resolver integrated with an angle-tracking observer provides accurate measurement of both absolute position and speed. Hoseinnezhad developed a robust estimator module that is stable in applications with high speed and acceleration [14]. A real-time adaptive estimator was investigated for the calibration of resolver parameters dependent on age and temperature [15]. Using these estimators, the resolver has been used to determine the clamp forces in brake-by-wire systems [8,13,14]. In contrast, force estimation based on the output of the incremental encoder has been studied only with a high resolution encoder, which provides over 8000 counts per revolution [8,12]. In this paper, we show that a low resolution encoder can be used for force estimation. In a previous study, a nonlinear control method was applied to the EPB system and it showed improved robustness and tracking performance compared to those of linear and on–off controllers [16]. However, this method requires an additional electric circuit to drive a DC motor. In this paper, we use an on–off control method for the force control logic to supply the maximum voltage until the clamping force reaches the desired final force. Using this method, the DC motor continues to rotate after the power is cut-off due to its momentum, resulting in an excessive clamping force. For functions that need fast or repeated apply-release operations such as anti-lock brake systems (ABS) and drive-away release, the excessive clamping force may cause a longer release time. Thus, the excessive force caused by the inertia effect should be compensated for. By compensating for the inertia effect through the novel on–off control method, our control logic can be implemented using a simple control unit without a PWM driver.

This paper focuses on a low cost and simple mechanism for both force estimation and control of an EPB system. Our proposed

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