Research on Regenerative Braking Algorithm for New Energy Vehicles

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Abstract. This paper introduces the research status of regenerative braking abroad, expounds the typical regenerative braking algorithm, and introduces the overall structure of the integrated control algorithm of regenerative braking and stability. By comparing regenerative braking and ESP coordinated control algorithm, ABS and ESP coordinated control algorithm and dynamic coordinated control algorithm, the theoretical limitations, advantages and disadvantages of typical regenerative braking algorithm are discussed. It provides material for studying regenerative braking algorithm.

Keywords: Regenerative Braking, Control Algorithm, ESP Coordinated Control

1. Introduction

Regenerative braking, also known as feedback braking, converts kinetic energy into heat in the form of friction. Regenerative braking converts kinetic energy into heat during braking and stores it instead of turning it into useless heat. Regenerative braking refers to the conversion of vehicle kinetic energy into other forms of energy storage through various energy conversion devices such as inverters connected to the driving wheel or driving shaft on the premise of meeting vehicle braking performance. The energy is then released as the vehicle starts or accelerates to increase the driving force on the driving wheels or shafts or thus increase the driving range. At present, the energy storage device commonly used in hybrid electric vehicles is usually the battery, so the common regenerative braking system is to convert the mechanical energy on the driving wheel (shaft) into electric energy through the energy conversion device and store it in the battery.

At present, there are two kinds of regenerative braking system: the first is to add solenoid valve on the traditional braking system to realize the regenerative braking function. At present, many energy-saving and new energy vehicles are modified on the basis of traditional vehicles. The advantage of this method is that regenerative braking can be realized only by modification on the traditional braking system. However, due to the structural limitations of the traditional braking system, this modification method has certain constraints on regenerative braking technology, which can not fully coordinate the electric mechanism force and mechanical braking force, and can not achieve the optimal energy saving effect. The second method is to apply a new type of electronic control braking system, based on the electronic control braking system to achieve regenerative braking. Because the electronic control
braking technology is completely controlled by the electric signal real braking force, it can be directly applied to regenerative braking technology. For example, Toyota Prius, currently the best-selling car in the world, uses the electric hydraulic braking system (EHB). In commercial vehicles, EBS also adopts electronic control braking technology, which is currently recognized as the development trend of electronic control braking system for commercial vehicle chassis in the future. Its hardware system can also directly meet the demand of regenerative braking for energy saving and new energy vehicles. Therefore, regenerative braking can be realized only by adding software control algorithm module on the basis of EBS. At present, there are many kinds of regenerative braking control strategies. The following will introduce the domestic and foreign regenerative braking control strategies in detail.

2. Research Status of Regenerative Braking

2.1. Regenerative braking force distribution and coordination control
In regenerative braking system of braking force distribution, regenerative braking system and mechanical brake system coordinated control and integrated ABS control aspect, the United States of Texas A&M university yi-min gao, Mehrdad Ehsani etc. It has been put forward in the 90 s, three so far are classic regenerative braking force distribution strategy [1], and under different conditions of the control strategy has carried on the simulation analysis. Then, based on the anti-lock braking system, a new regenerative braking control strategy is proposed, which distinguishes the distribution logic of conventional braking and emergency braking modes, and realizes integrated control by controlling the electric mechanism dynamic threshold value. However, there is not much research on the coordinated control of the two systems [2]. Panagiodis of Mihatian, USA, has studied a hybrid braking system, analyzed the performance of regenerative braking system through modeling and simulation, and analyzed various factors that affect the braking energy recovery effect of regenerative braking system [3]. Ford Research Institute Cikanek also studied regenerative braking system based on parallel hybrid electric vehicles, focusing on how to improve the braking performance and efficiency of regenerative braking system while reducing costs [4]. Konghyeon Kim et al. from Sungkyunkwan University in South Korea studied the regenerative braking system of four-wheel drive hybrid electric vehicle and put forward the corresponding braking force distribution strategy for the regenerative braking system. Based on the proposed distribution strategy of regenerative braking, the integrated control of regenerative braking system, hydraulic braking system and ABS system is further studied. Fuzzy control idea is adopted to realize the integrated control of the three parts of the braking system [5].

2.2. Integrated control of regenerative braking and stability control
As for the integrated control of regenerative braking system and stability control system, Hancock.Matthew et al. studied the influence of the intervention of regenerative braking system in rear-drive vehicles on vehicle stability. Studies show that there is a certain contradiction between braking energy recovery and braking stability. In general, in order to improve energy recovery, the rear axle should be braking as much as possible. However, if the vehicle is on a low-adhesion road surface, the increase of braking force of the rear axle may lead to the loss of vehicle stability. In order to prevent vehicle instability, the driving shaft torque distribution device can be used to redistribute the braking force under the condition of low adhesion [6]. Donghyun Kim proposed the coordinated control algorithm of regenerative braking and stability of four-wheel drive hybrid electric vehicle (the front axle is jointly driven by engine and motor, and the rear axle is only driven by motor) [7]. Masayuki Soga et al. proposed an integrated control algorithm of regenerative braking and stability based on electronic braking system with the goal of recovering braking energy as much as possible under the premise of ensuring vehicle braking stability [8]. The robustness of the control algorithm can be improved by using the method of linear quadratic regulator to design feedback gain.
2.3. Vehicle stability control
Vanzanten introduced Bosch's vehicle stability control algorithm, which uses an optimal control method by optimizing the distribution of braking force on wheels to ensure vehicle handling stability in the case of oversteer and understeer. M.Mirzaei adopted the optimal control method of minimum energy consumption to study the vehicle stability control algorithm, which could guarantee the stability of the vehicle on the premise of the minimum braking energy consumption, so as to ensure that the vehicle speed was basically unchanged in the whole control process. Hattori.Y and Koibuchi.K Yokoyama.T adopted the nonlinear optimization method to distribute the braking force of the wheel, which could maintain the stability of the vehicle on the premise of ensuring the driver's driving force or braking force demand [9]. Kihongpark, Seung Jin Heo and Inho Baek adopted the feedback control method to design the vehicle stability control algorithm.

2.4. Several classic regenerative braking systems
The TOYOTA - PRIUS braking control system consists of hydraulic braking controlled by a braking controller and regenerative braking controlled by a vehicle controller. Eco-Vehicle braking control system is shown in Figure 1 [10], which is modified on the basis of conventional Vehicle braking system. Pressure control valves are added between the master cylinder and the front and rear axles. Its role is to control the front and rear wheel brakes, reduce the proportion of hydraulic braking force. In addition, a mechanical device is also provided in the pressure control valve unit to reduce the vibration of the pedal when the pressure fluctuates.

![Figure 1. Toyota-Prius Brake control system](image)

3. Several typical regenerative braking algorithms

3.1. Overall structure of regenerative braking algorithm
Fig. 2 is the overall block diagram of the integrated control system for regenerative braking and stability. The integrated control system of regenerative braking and stability mainly includes regenerative braking force distribution module, ABS/ESP controller, regenerative braking and stability coordination controller module, hydraulic control unit and motor controller.
Figure 2. Block diagram of regenerative braking and stability integrated control system

4. Conclusions
In this paper, several typical regenerative braking algorithms are introduced, and the overall structure of the integrated regenerative braking and stability control algorithm is studied.

1. Coordinated control algorithm of regenerative braking and ESP. Algorithms were studied by switching control ESP working mode, regenerative braking process mode and ESP exit working mode, etc. The limitation of this method is that braking force and distribution mode of front and rear wheels need to be recalculated when switching different modes.

2. ABS and ESP coordination control algorithm, through the calculation of wheel slip rate incremental feedback to control the coordination of ABS controller and ESP controller. The error of slip ratio calculation directly affects the accuracy of the control algorithm.

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