Review on the design structure and research implemented on electronic wedge brake

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ABSTRACT – In this paper, an overview of electronic wedge brake (EWB) design and control is presented. The related issues of brake-by-wire are also raised, whereas the types of brake-by-wire are explored. Furthermore, the discussion on implementations of EWB in vehicles as well as in ABS system is also presented to provide better insight into the application of EWB in vehicle braking system.

1. INTRODUCTION

Brake system is one of the most important mechanical component in any moving vehicles. This system must be able to provide sufficient stopping effort in order to control the longitudinal motion of the vehicle. Braking force is delivered to a moving vehicle by creating frictions that are applied to the rotating axles or wheels. In general, braking system can be classified into several categories depending on the mechanisms that provide the braking force, such as pumping brake, electromagnetic brake and frictional brake (Betin et al. 2002).

Pumping brake consists of a piston motor within the mechanism and usually place in the internal combustion engine. The piston motor stops the fuel supply which in turns generate braking effect to the vehicle [1, 2, 3]. On the other hand, electromagnetic brake comprises of an electric motor in the brake calliper mechanisms, which acts as a medium to supply the braking force [3]. Meanwhile, frictional brake adapts the concept of friction between two surfaces to absorb the energy and thus, slowing down the wheel rotation [4]. In frictional brake, there are two common approaches that are used in the brake mechanism, which are the shoes and pads. They are located on the wheel to exert friction on the wheel surface when the brake is applied [5].

2. THE EWB

Inspired by the introduction of "x-by-wire" technology, a new braking system namely electronic wedge brake (EWB) has been developed as a solution to overcome the drawback of the CHB. The EWB is a pure electronically controlled actuator that typically comprises of an electric motor driving the wedge mechanism to clamp and release the brake rotor. As a result, it has a great potential to improve vehicle safety by reducing the braking time as well as allowing a full integration of advanced control features.

The research and development of EWB is motivated by a number of its potential benefits. By comparing to CHB, it offers advantages such as component quantity reduction, weight reduction and brake response improvement [27-28]. EWBs also support the vision of drive-by-wire, where a communication network liberates the vehicle control from the constraints of mechanical linkages. It can also increase cabin space with ergonomic and crash compatible controls [28]. By looking further ahead, this system has the potential to support autonomous vehicles configuration [29, 30].

2.1 The concept of EWB

The concept of EWB was firstly initiated by German Aerospace Centre (eStop®-GMBH) where a simple and efficient EWB mechanism was proposed [7]. The design was equipped with electric powered DC motor and wedge mechanism that was in direct contact to the brake lining. The electric motor triggered the brake lining to rotate in opposite direction against the rotational movement of the wheel until the wedge mechanism stuck at the abutment. However, there was a noticeable problem arising, where the brake jammed after being applied [7]. To overcome the jamming problem, the (eStop®-GMBH) came out with the second and third generations of EWB namely Alpha and Beta prototypes that incorporated two brushless DC motor to push and release the wedge mechanism during braking [8]. Even though this problem had been solved, the structure became more complex compared to the earlier design. Furthermore, it was necessary to take into account the high-cost and reliability of the usage of double motors.

2.2 EWB actuator

In line with the intention to overcome the wedge jammed at the abutment and the drawback in the use of the double motor, researchers thereafter had refocused to develop an EWB based on a single motor [9-25] by replacing the used actuator [15-17, 19]. By assuming that a greater pulling force was needed to pull back the wedge from jammed, some researchers replaced the DC motor with a normally retract solenoid actuator [15-17] and variable force solenoid actuator [19]. Apart from that, several researchers still maintaining the use of DC motor in the EWB design by adding some additional features, such as pushrod non-self-locking screw to push and release functions [11]; roller bearing as the abutment [12]; and a worm gearing system to actuate the wedge mechanism [13]. From the conducted experiments, these additional features were very effective in preventing wedge mechanism from getting jammed, thus become a common feature in the EWB design [22-25].

2.3 Wedge Mechanism

Despite the favourable introduction of the additional features into the EWB design, a little attention was given to the study on the wedge angle profile. Regardless the types of EWB, most of them were still using the same wedge angle [7-25], without taking into account on how to select the optimum wedge angle to effectively reduce the force required to pull out the wedge from the abutment. The only difference in the design were the shape of the wedge and/or the arrangement of the wedge mechanism in the braking system, which were V type [9], W type [24], cross type [8] and spiral type wedge profiles [18]. However, the angle of the wedges in these types of mechanism had not been properly optimized. Therefore, any proposed improvement to the wedge profile will not improve the jamming problem.

2.4 EWB mathematical modeling

Concurrently, extensive investigation of the EWB especially on mathematical modelling and control of the EWB system had been developed and validated [8, 9, 21-28, 30-31, 34]. However, the validation results of the EWB models as reported in [8, 9, 21-28, 30-31, 34] showed that there were more than 30 percent disparities between simulation and experimental results. It was caused by the simplification, idealization as well as the modelling technique used during modelling of the brake system. Generally, in modelling of a dynamic system, there are two techniques commonly used, namely physical parametric estimation method (PPEM) and system identification method (SIM) [32, 33]. PPEM is referred to the modelling method in which the characteristics of the system are represented as linear and non-linear elements with some defined parameters [32, 33]. Under normal circumstances, SIM is more accurate since it is developed based on experimental input output data. In contrary, PPEM is less accurate due to the limitation of the PPEM technique that requires several assumptions and potentially degrades the adequacy of the model.

2.5 EWB testing

In another area of study, the functionality testing of EWB in vehicle braking system had been conducted including in the active braking system, especially in ABS [8, 9, 24, 29, 34-38]. However, in these researches, the aims of the studies were limited to examine the usability of the braking system which depended on the performance of the low-layer actuator controls, and not focusing on the ABS control development. Almost all researchers who developed the ABS control in EWB were using conventional Bang-bang controller [8], PID controller [9, 24, 29, 36, 37], Fuzzy Logic Controller (FLC) [29,38] and Sliding Mode Control (SMC) [20]. It was a common fact that those proposed controllers had limitations, such as linearity in PID [39-40], static rules in FLC [41] and slow learning speed in SMC [42, 43]. It can be concluded that the effectiveness of ABS in EWB for ABS is not fully exploited yet based on previous researches [44].

2.6 EWB implementation

Besides that, the research of the EWB in a real vehicle environment is still in an early stage. There are still many considerations that need to be resolved before the system can be implemented in the real vehicle. This must be done carefully in order to reduce excessive operating costs, time and to prevent failure during experiment. Some researchers had implemented the system experimentally using a quarter car test rig [8, 9, 24 31, 37] and a real vehicle [35, 37]. However, the obtained experimental results showed some delay in response signal and not concur with related theories [24, 35, 37] due to the malfunction of the system and the safety issues. These findings indicate that there is another step needed to be executed before the experimental study in a real vehicle can be conducted.

3. RESEARCH GAP

3.1 Results of sheet resistivity

From the previous sections, the timeline of vehicle BBW system has been reviewed. It should be noted that recently, the electromechanical brake (EMB) are getting more attention than other BBW technologies due to several advantages such as purely electronic control, faster response and more reliable compared to hydraulic fluid and pneumatic system which are more prone to mechanical failure. Based on EMB technology, the EWB has been introduced by replacing the existing piston mechanism with a wedge mechanism that is more attractive, simpler in design and requires less power. The latest development of BBW system in automotive industries is going towards the use of EWB. Despite successful achievements in producing various designs of EWB over the last decade, more effort is still needed to increase the capability and usability of EWB in automotive applications.

From these explanations in the research background, it can be observed that the research on EWB has significant impact to the advancement in automotive technology. Even that so, thorough studies of the system are still lacking and have some limitations that need to be solved. The lacking of the studies in EWB is listed as follows:

a. In the existing EWB designs, the wedge mechanism is stuck at the abutment, because of the wedge‘s shape is not properly optimized.
b. The validation results of the EWB model between simulation and experiment produce high percentage of disparities.
c. The functionality of the EWB has been tested up to ABS usage, but the effectiveness of the EWB equipped with ABS is not fully exploited yet because the development of ABS controllers is based on basic controller only
d. Problem in implementing the EWB in the real vehicle system due to several safety issues

4. SUMMARY

The overview of EWB design, wedge mechanism, EWB modeling techniqueand the applications of EWB in vehicle braking system have been presented. The explanations of EWB design have been elaborated based on its wedge mechanism and its actuators. Thereare many types of EWB has been developedbut in general, researchers have determined that most of the designed EWBs are based on the floating caliper type. Besides that, the explanations of the EWB dynamic model were conducted based on the categorization ofmodeling technique types, namely the PPEM and the SIM.Among those methods, the PPEM is the most popular and commonly used to model the dynamic behavior of the EWB, even so, it has limitation in performance accuracy which promotes the discussion of SIM that has advantages in mock-upping the behavior of a real system more precisely. Furthermore, the most recent study that explored the testing of the EWB in vehicle braking system also has been covered up to the application in the ABS. The discussioncover the control technique approaches that often used in common ABS based CHB and in ABS based EWB. It is noted that, in term of ABS based EWB, the focus are to test the capability of the brake actuator only and did not emphasizes the development of the ABS control itself.Additionally, the experimental investigation of the EWB in real vehicle system also has been exposed and seen have several drawbacks which than initiating the discussion of HILS technique.

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