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Research on Regenerative Braking Systems: A Review

Bekir GÜNEY[1], Halil KILIÇ[2]

[1]Karamanoglu Mehmetbey University, Vocational School of Technical Sciences, Karaman, 70200, Turkey, *guneyb@kmu.edu.tr*

[2]Kırklareli University, Vocational School of Technical Sciences, Kırklareli, 39200, Turkey, *halil.kilic@klu.edu.tr*

Abstract: ***Regenerative braking systems (RBS) are an effective method of recovering the energy released and at the same time reducing the exhaust and brake emissions of vehicles. This method is based on the principle of converting the kinetic energy created by the mechanical energy of the motor into electrical energy. The converted electrical energy is stored in the battery for later use. This braking system must meet maximum energy recovery criteria by performing its function safely within the shortest braking distance. This study was conducted to provide comprehensive information about regenerative energy systems. These systems provide economic benefits via fuel savings and prevention of material loss. Their use also contributes to a clean environment and renewable energy sources, which are among the most important issues on the global agenda. It is clear that more comprehensive studies should be carried out in this area.***

Keywords: Regenerative brake, Energy, Vehicle, Emission, Fuel saving, Clean air

1. Introduction

Due to the rapid increase in the world population, the number of vehicles is also rising. Serious threats to the environment and human health brought about by vehicle-related emissions include air pollution, global warming, and the rapid depletion of petrol resources. These problems force countries to take measures to ensure clean air, energy savings, and novel energy applications. In addition, the resulting worldwide energy crisis compels nations to turn to alternative energy sources and to retain maximum energy from existing resources. Regenerative braking systems are among these important energy saving applications.

Electric vehicle systems constitute one area to which RBS can be widely applied. These vehicles have become highly popular in recent years due to their significant fuel economy and minimum vehicle emissions. In order to both drive the vehicle and recover significant amounts of braking energy, electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell hybrid electric vehicles (FCHEVs) have one additional electric motor. In EVs, HEVs, and FCHEVs, this is one of the most important units for saving fuel and energy. Although this unit has the same characteristics as in conventional vehicles, it enables the storage of the vehicle's energy during driving and braking. This braking energy stored in the system can be reused [1].

For this reason, EVs, HEVs, and FCHEVs are of great interest as alternatives to conventional internal combustion engine (ICE) vehicles [2]. This may result from the increased awareness of global warming and rising fuel costs. Therefore, these vehicles are in high demand due to the alarming increase in air pollution and petrol prices [3]. These vehicles have the advantages of low emission, low noise, and high energy efficiency, all of which have become the focus of research in the automotive industry [4-6]. Currently, the switched reluctance motor (SRM) is considered one of the best options for operating EVs because of its advantages of simple structure, low cost, high reliability, high power generation, and high efficiency at a wide range of speeds [7, 8]. Meanwhile, the traction system with SRM can recover more energy during regenerative braking conditions. However, SRMs have the disadvantage of high torque fluctuations [9] that directly affect the braking comfort and stability of the vehicle.

Another major disadvantage of purely EVs is the use of batteries as the only energy source, which causes problems because of long charging time, low specific power, and the inability to meet the short-term power requirements of the vehicles. Therefore, the acceleration, climbing, braking performance, and energy recovery efficiency of the motor are seriously affected and the power requirements of the vehicle on the motor cannot be fully met [2-3]. However, the advantage of the EV is that as the energy storage system, the battery has high energy density and a very large storage capacity [10]. Moreover, advanced battery technology offers a longer service life for batteries [11]. In this way, EVs use the RBS to increase energy efficiency by recovering some of the braking energy. However, under different braking conditions, the feedback current produced by the generator is substantially high [12]. High levels of charging current can shorten the cycle life of the battery [13, 14]. However, the energy recovery rate of the energy storage system may not reach the desired level due to the limitation caused by the characteristics of the motor and battery [15]. The high cost of batteries and the limitations of their use in heavy vehicles are also disadvantages of these new-generation vehicles[16].

The abovementioned restrictions can be overcome by using ultracapacitors, flywheels, electrochemical batteries, and similar energy sources in addition to the battery [3]. Regenerative braking was developed to overcome this problem as a process in which some of the kinetic energy generated during deceleration in vehicles is stored in the battery and ultracapacitor [17]. However, the RBS may not always work when the vehicle is forced to apply the brakes on a stable road, as seen with vehicle speed-bumps and potholes in the road [18].

In addition, although the energy density of the hydraulic energy storage system is substantially low, it has the characteristics of a high-power density device (hydraulic accumulator) [19], and thus has the potential to overcome the shortcomings of an electrical energy storage system. The hydraulic system is used to absorb the high-power braking energy and release the stored energy during starting or acceleration. This has the potential to increase energy efficiency and reduce over current and consequently, to extend the driving range of the vehicle and prolong the cycle life of the battery. The hydraulic energy storage system is used to improve fuel economy in conventional ICE vehicles. The hydraulic system can recover about 80% of the braking kinetic energy and deliver it to the wheels. This hydraulic hybrid system has been reported to reduce fuel consumption by 45% during urban use [20]. The energy efficiency of a vehicle can generally be improved in three ways:

1) By operating each component at optimum efficiency.
2) By reducing tire rolling resistance and curbing aerodynamic and transmission losses.
3) By recovering the kinetic and potential energies commonly generated in the form of heat in the brakes.

Operating each component with optimum efficiency can be accomplished by correctly selecting the component type, component size, configuration, and control strategy. Thus, the components can function in a coordinated and harmonious manner under all operating conditions. Ever since the invention of the automobile, the goal of automobile engineers has been to reduce tire-rolling resistance and curb aerodynamic and transmission losses, and great efforts on behalf of these issues are still being made today. Moreover, recovery of vehicle kinetic and potential energies has been recognized as one of the most effective approaches to increase vehicle energy efficiency and boost stop-and-go vehicle efficiency. For example, a 1500-kg vehicle traveling at 70 $km.h^{-1}$ will store approximately ½ × 1500 × 20^2 = 300,000 J = 300 kJ of kinetic energy. If the kinetic energy of this vehicle at 70 km / h can be fully recovered and transformed, this recovered energy has the potential to drive the vehicle forward for a distance of approximately 1.8 km. However, because of various friction mechanisms, this distance in reality is shorter, and not all the kinetic and potential energy of the vehicle can be recovered and recycled. In EVs and HEVs, only the driven axle is effective for regenerative braking. In the braking system, some of the braking energy is dissipated as heat via the friction of the non-driven axle. Moreover, losses occur in vehicles that use energy recovery and conversion. One major problem is that because a part of the braking energy is absorbed when the braking power requirement exceeds the capacity of the RBS, the amount of energy recovered by the friction braking system is reduced. Therefore, when designing an RBS, a correlation must be established between the amount of regenerative braking energy and the structure, development time, cost, and braking reliability of the system [21].

Brake systems are expected to control the speed of a vehicle under all road conditions and to stop it safely [22-29]. The slowing down of a vehicle having a conventional brake system requires the kinetic and potential energy of the vehicle to be converted into thermal energy or heat as a result of the frictional effect. Studies have shown that approximately one-third of the energy produced by a vehicle during urban driving is consumed by braking [21, 30]. In HEVs, kinetic energy generated by regenerative braking can be converted into electrical energy that can be stored in batteries to propel the vehicle during the driving cycle [30]. Regenerative braking has the potential to conserve energy by boosting fuel economy, while reducing emissions that cause air pollution [15]. There are two versions [32] of regenerative braking. The first type is the series regenerative braking based on a combination of a friction-based adjustable braking system and a regenerative braking system that transfers energy to electric motors and batteries under an integrated control strategy. The second type is a friction-based parallel braking system in which the regenerative braking system is operated sequentially without an integrated control [33]. The parallel RBS has the advantage of a simple structure and can be used without modification in existing friction braking systems. However, the amount of energy recovered by the RBS is small and the vehicle range may be adversely affected. On the other hand, the implementation of a series RBS is more complex than with the parallel RBS, but the energy recovered is higher and the drive ability of the vehicle can be maintained [15]. Regenerative braking is observed only when the battery is fully charged and needs to be performed by releasing energy, and therefore, EVs require mechanical brakes. Electric vehicles use mechanical brakes to increase the roughness of the wheel for deceleration. Easily controlled motors can be regenerated. In two-wheel EVs, mechanical brakes are often used to stop or slow the vehicle; kinetic energy stored in vehicles is lost during braking [34]. The kinetic energy lost during braking can be converted back into electrical energy and stored in the battery or ultracapacitor. If this energy is properly managed, it can be carefully controlled without causing any problems for the motor, driver, or battery [18].

In EVs, the driving range is increased by combining mechanical braking and regenerative braking systems. In recent years, many studies have been carried out on improving the braking system performance of EVs, including the topics of EV energy management [35], emergency brake control strategies [36] and anti-lock braking systems (ABS) [37], mechanical and maximum regenerative braking force [38], braking reliability [39], increasing regeneration efficiency [40], improving driving distance [2], and vehicle lateral stability problems caused by the transition from regenerative braking to hybrid braking [41]. These studies mainly focused on maximum regenerative braking force, maximum energy generation, and braking stability. In addition, intensive studies are currently being carried out on the subjects of the switched reluctance generator (SRG) drive system control [22], efficient recovery of mechanical energy [42], power draw improvement [25], ripple reduction [7, 43, 44], and limiting of battery current fluctuation [45].

The biggest obstacle to energy recovery in EVs is the short driving range. The RBS includes an electric motor that applies negative torque to the driven wheels and converts the kinetic energy into electrical energy to charge the battery. The kinetic energy released during braking in EVs can advantageously be recovered by the electric motor equipped with a control unit acting as a generator. The recovered energy is stored in the battery for later use [31, 46].

The three main RBS control strategies for EVs include: maximum regenerative power control, maximum regenerative efficiency control, and constant regeneration current control. Regarding the power of the battery, it is necessary to limit the maximum charging current to within the range of 0.1 C (C is the capacity of the battery) to prevent excess regenerative current from damaging the battery. An EV requires long periods of braking when running on long gradients. However, the above two control strategies can damage the battery even if it achieves higher regenerative efficiency [47, 48]. For this reason, a cooperative regenerative braking control strategy is recommended to increase the recovery of braking energy while improving the lateral stability of the vehicle [49].

Braking is a process that prevents the movement of a mechanical or electrical device. Generally, it is necessary to brake a vehicle quickly and smoothly according to a certain speed program. The braking torque can be applied by using an electrical system, a mechanical system, or a combination of both. The speed and accuracy of the stopping operations increase the efficiency and reliability of a system. When starting electric drives, it is necessary to stop the engine quickly. A retarding torque can be applied either mechanically or electrically. In the mechanical operation, the braking motion is performed by the friction force between the rotating parts and the brake pads. On the other hand, in electric braking, a braking torque is developed that corresponds to the movement of the rotating element during the braking process. Electrical methods are more precise than mechanical methods, making accurate and timely control of the stopping possible. The braking torque is also required for parts of the duty cycle and for emergency braking in some applications such as winches. Reversing and speed control of the drives can also be performed by electric braking. In the event of electrical braking, the kinetic energy of the rotating parts is converted into electrical energy.

Braking in AC systems

The braking methods used in an asynchronous (AC) motor drive can be classified as follows:

a) Regenerative braking,

b) Plugging or reverse current braking,

c) Dynamic or DC rheostatic braking.

Braking in DC systems

Braking in direct current (DC) systems is again divided into three categories:

a) Regenerative braking,

b) Dynamic or rheostatic braking,

c) Plugging or reverse current braking.

Braking in Electric Vehicles

Brake systems used in electric vehicles can be of different types. Different types of systems can be used in EVs. For example, conventional friction brakes are used in some vehicles. In these systems, continuous braking is applied, which produces the friction necessary to slow the vehicle by stopping the wheels. In conventional brake systems, a significant amount of energy is lost due to the heating of the brake pads. Another brake system is the anti-lock brake system. In this system, braking is not applied continuously, but an intermittent braking procedure is used, which slows down or stops the vehicle when necessary. This system is more efficient than the traditional brake system and provides superior performance. Regarding our study, it is also possible to see the RBS system widely in use. The RBS includes an electric motor. This electric motor is used as a driver. When the brake pedal is pressed in an EV, the mechanism tends to move the motor in the opposite direction, thereby slowing the vehicle by generating a torque in the opposite direction. During braking, the motor works as a generator that re-energizes the battery and at the same time slows down the vehicle. Another circuit can also be used to direct the motor current generated during braking of the vehicle. Such systems also charge the battery and aid in braking. However, regenerative braking systems cannot be used alone because they have only a slow down feature and cannot stop the vehicle completely. Therefore, such systems are used in conjunction with conventional friction brakes or ABS [50].

In regenerative braking systems, by integrating the electric motor on the front and rear wheels, many advantages can be gained from the system compared to conventional vehicles. First, the additional torque coupling mechanism can be eliminated. Second, when the torque needed is relatively large, four-wheel drive can be executed. Finally, during the deceleration process, the electric motor can be used as a generator by applying regenerative braking [51], and thus providing fuel economy with the energy recovery from the regenerative braking [52]. This electrical energy can then be stored in energy storage systems (e.g., batteries or ultracapacitors) and left as driving means for the electric motors when required. The regenerative and mechanical braking systems must be fully integrated to enable regenerative braking to operate reliably and effectively. In order to meet the demand of the driver, this integration requires smooth and accurate control of the combined regenerative and mechanical braking [53]. Therefore, a harmonious operation between the hydraulic brake system and the regenerative brake system is an important element in the design of HEV brake control strategy [54].

2. Working Principle of Regenerative Braking System

Regenerative braking is a braking method that provides charge to the battery by converting the mechanical energy of the motor and kinetic energy into electrical energy. In regenerative braking mode, the car's engine slows down on an incline. When force is applied to the brake pedal, the vehicle slows down and the motor runs in the opposite direction. When operating in the opposite direction, the engine acts as a generator and converts torque energy into electrical energy. In this way, fuel consumption and emissions are reduced. In high-speed vehicles, the braking force is lower, and therefore does not adversely affect the traffic flow [55].

The new electric-hydraulic powertrain is a parallel hybrid system that includes a traction motor, battery pack, hydraulic pump / motor (secondary component), hydraulic accumulator, reservoir, and a set of hydraulic valves. The hydraulic circuit includes the drive circuit and the drain circuit. The drive circuit consists of a cartridge valve, a one-way valve, and a two-position four-way valve. When the vehicle is braking, the valve is shifted to the left; this directs the oil from the reservoir to flow towards the accumulator using the secondary component pump / motor. The secondary component operates in pump mode, using the kinetic energy of the vehicle to pressurize the oil in the reservoir to flow into the accumulator. The energy is stored in the accumulator and the vehicle slows down. The hydraulic system works in the regenerative braking mode [20].

These brakes work very effectively in urban braking situations. The brake system and control sensors are programmed to control all of the vehicle motors. The brake control sensor calculates the electricity to be generated and the rotational force to be fed to the batteries by monitoring the speed and torque of the wheel. During braking, the brake control sensor controls the electrical energy generated by the motor and directs it to the batteries [17].

2.1 Series Regenerative Braking System

The vehicle's power train includes an auxiliary power unit (APU), which consists of an internal combustion engine connected to a generator and rectifier that can start the electric motor or recharge the batteries as requested by the vehicle control unit (VCU).The electric motor controlled by the motor control unit can act as a drive motor or a generator. During regenerative braking, while the motor is operating as a generator, the battery can start the motor or absorb current from the APU and the electric motor. The framework of the RBS series consists of the RBS, the ABS and two duty valves used to adjust the friction braking force. Working valves are installed on the front and rear brake lines. Elements used in the ABS can be used for this purpose and have a rapid response time. The different states of the two valves determine the air pressure in the brake chambers. The brake control unit controls the mechanical braking force under the command of the RBS control system by sending pulse width modulation (PWM) signals to the valves to control the pressure. When the electronic control unit (ECU) detects a lock on one of the rear wheels, the ABS controller emits a signal that will cause the brakes to vibrate to activate the modulator valve, thereby easing the wheel lock state. Since the RGS is mounted on the rear axle, the same signal can be used to control the regenerative braking force and to increase vehicle stability by minimizing wheel lock during hard braking operations [15].

2.2 Parallel Regenerative Braking System

During parallel regenerative braking, both the electric motor and the mechanical braking system always work together in parallel to slow down the vehicle [56]. Energy regeneration during braking is important for a parallel HEV because it enables the vehicle to improve fuel economy and extend its driving range. To increase energy use during braking, the electric motor applies a negative torque to the wheels to convert some of the vehicle's kinetic energy into electrical energy to recharge the battery [57, 58].

Since the mechanical braking process cannot be controlled independently of the brake pedal force, some of the kinetic energy of the vehicle is converted into heat, not electrical energy. The regenerative braking force developed by the electric motor is a function of the hydraulic pressure of the master cylinder and therefore a function of vehicle deceleration. Since the available regenerative braking force is a function of the motor speed and almost no kinetic energy can be recovered at low motor speeds, in order to maintain brake balance, the regenerative braking force is designed to be zero at high-speed deceleration. A pressure sensor detects hydraulic pressure indicating the demand for deceleration in the master cylinder. The pressure signal is regulated and sent to the electric motor controller to control the electric motor in producing the desired braking torque. Moreover, the parallel regenerative braking system is simple and inexpensive. With this method, the electric motor can be integrated into the system with a small modification on the mechanical brake system. In addition, there is the advantage of always having a back-up mechanical brake system in cases where repeated brake system failure occurs [53].

3. Conclusions

This study presents information about the principles and properties of regenerative braking systems. Many automation, electromechanical, and constructive studies have been carried out in this field in order to boost recovered energy efficiency and reduce operating costs. Considering that most of the economic losses worldwide are caused by mechanical wear, the importance of regenerative braking systems has become better recognized. Safety, comfort, and economic aspects can be increased by developing these brake systems. Regenerative braking systems, currently in limited use in electric vehicles, can also be used in conventional braking or other motion control systems. When they are widely used, economic input can be obtained by the reduction of mechanical losses and energy savings can be achieved as a result of the recovered electrical energy. In addition, vehicle emissions caused by conventional brake wear can be reduced, thus contributing to the protection of the environment and human health. As a result, these systems emphasize the recovery of energy, reduction of energy consumption, lowering of costs, and provision of clean air. For this reason, more comprehensive studies in the field of regenerative braking systems should be carried out and their findings presented to policy makers and researchers.

References

[1] Han, J., & Park, Y. (2014). Cooperative regenerative braking control for front-wheel-drive hybrid electric

vehicle based on adaptive regenerative brake torque optimization using under-steer index. *International Journal of Automotive Technology*, *15*(6), 989-1000.

[2] Nian, X., Peng, F., & Zhang, H. (2014). Regenerative braking system of electric vehicle driven by brushless DC motor. *IEEE Transactions on Industrial Electronics*, *61*(10), 5798-5808.

[3] Bobba, P. B., & Rajagopal, K. R. (2012, December). Modeling and analysis of hybrid energy storage systems used in electric vehicles. In *2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)* (pp. 1-6). IEEE.

[4] Huang, Y., Wang, H., Khajepour, A., He, H., & Ji, J. (2017). Model predictive control power management strategies for HEVs: A review. *Journal of Power Sources*, *341*, 91-106.

[5] Boldea, I., Tutelea, L. N., Parsa, L., & Dorrell, D. (2014). Automotive electric propulsion systems with reduced or no permanent magnets: An overview. *IEEE Transactions on Industrial Electronics*, *61*(10), 5696-5711.

[6] Tang, X., Yang, W., Hu, X., & Zhang, D. (2017). A novel simplified model for torsional vibration analysis of a series-parallel hybrid electric vehicle. *Mechanical Systems and Signal Processing*, *85*, 329-338.

[7] Sikder, C., Husain, I., & Sozer, Y. (2013). Switched reluctance generator control for optimal power generation with current regulation. *IEEE Transactions on Industry Applications*, *50*(1), 307-316.

[8] Rahman, K. M., Fahimi, B., Suresh, G., Rajarathnam, A. V., & Ehsani, M. (2000). Advantages of switched reluctance motor applications to EV and HEV: Design and control issues. *IEEE transactions on industry applications*, *36*(1), 111-121.

[9] Ding, W., Liu, G., & Li, P. (2019). A hybrid control strategy of hybrid-excitation switched reluctance motor for torque ripple reduction and constant power extension. *IEEE Transactions on Industrial Electronics*, *67*(1), 38-48.

[10] Borba, B. S. M., Szklo, A., & Schaeffer, R. (2012). Plug-in hybrid electric vehicles as a way to maximize the integration of variable renewable energy in power systems: The case of wind generation in northeastern Brazil. *Energy*, *37*(1), 469-481.

[11] Lu, L., Han, X., Li, J., Hua, J., & Ouyang, M. (2013). A review on the key issues for lithium-ion battery management in electric vehicles. *Journal of power sources*, *226*, 272-288.

[12] Onda, K., Ohshima, T., Nakayama, M., Fukuda, K., & Araki, T. (2006). Thermal behavior of small lithium-ion battery during rapid charge and discharge cycles. *Journal of Power sources*, *158*(1), 535-542.

[13] Schaltz, E., Khaligh, A., & Rasmussen, P. O. (2008, September). Investigation of battery/ultracapacitor energy storage rating for a fuel cell hybrid electric vehicle. In *2008 IEEE vehicle power and propulsion conference* (pp. 1-6). IEEE.

[14] WU, Y., JIANG, X. H., & XIE, J. Y. (2009). The reasons of rapid decline in cycle life of Li-ion battery [J]. *Battery Bimonthly*, *4*(39), 80-82.

[15] Zhang, J., Lu, X., Xue, J., & Li, B. (2008). Regenerative braking system for series hybrid electric city bus. *World Electric Vehicle Journal*, *2*(4), 363-369.

[16] Amjad, S., Rudramoorthy, R., Neelakrishnan, S., Varman, K. S. R., & Arjunan, T. V. (2011). Evaluation of energy requirements for all-electric range of plug-in hybrid electric two-wheeler. *Energy*, *36*(3), 1623-1629.

[17] Guo, J., Wang, J., & Cao, B. (2009, June). Regenerative braking strategy for electric vehicles. In *2009 IEEE Intelligent Vehicles Symposium* (pp. 864-868). IEEE.

[18] Malode, S. K., & Adware, R. H. (2016). Regenerative braking system in electric vehicles. *International Research Journal of Engineering and Technology (IRJET)*, *3*(3), 394-400.

[19] Niu, G., Shang, F., Krishnamurthy, M., & Garcia, J. M. (2016, June). Evaluation and selection of accumulator size in electric-hydraulic hybrid (EH2) powertrain. In *2016 IEEE Transportation Electrification Conference and Expo (ITEC)* (pp. 1-6). IEEE.

[20] Yang, Y., Luo, C., & Li, P. (2017). Regenerative braking control strategy of electric-hydraulic hybrid (EHH) vehicle. *Energies*, *10*(7), 1038.

[21] Gao, Y., Chen, L., & Ehsani, M. (1999). Investigation of the effectiveness of regenerative braking for EV and HEV. *SAE transactions*, 3184-3190.

[22] Güney, B., & Mutlu, I. (2019). Tribological properties of brake discs coated with Cr_2O_3-40% TiO_2 by plasma spraying. *Surface Review and Letters*, *26*(10), 1950075.

[23] Guney, B., Mutlu, I., & Gayretli, A. (2016). Investigation of braking performance of NiCrBSi coated brake discs by flame spraying. *Journal of the Balkan Tribological Association*, *22*(1 A), 887-903.

[24] Güney, B., & Mutlu, İ. (2017). Dry friction behavior of NiCrBSi-%35W_2C coated brake disks. *Materials Testing*, *59*(5), 497-505.

[25] Mutlu, İ., Güney, B., & Erkurt, İ. Investigation of the effect of Cr_2O_3-2%TiO_2 coating on braking performance. *International Journal of Automotive Engineering and Technologies*, *9*(1), 29-41.

[26] Mutlu, İ., Güney, B., Ünal, O. C., & Kartal, Ö. 55TiO_2-Cr_2O_3 Kaplamanın Frenleme Performansına Etkisinin Araştırılması. *Nevşehir Bilim ve Teknoloji Dergisi*, 1-15.

[27] Kılıç, H., & Mısırlı, C. (2020). Investigation of tribological behavior of 20NiCrBSi-WC12Co coated brake disc by HVOF method. *Materials Research Express*, *7*(1), 016560.

[28] Mutlu, I., Eldogan, O., & Findik, F. (2005). Production of ceramic additive automotive brake lining and investigation of its braking characterisation. *Industrial Lubrication and Tribology*.

[29] Öz, A., Gürbüz, H., Yakut, A. K., & Sağiroğlu, S. (2017). Braking performance and noise in excessive worn brake discs coated with HVOF thermal spray process. *Journal of Mechanical Science and Technology*, *31*(2), 535-543.

[30] Ehsani, M., Gao, Y., & Butler, K. L. (1999). Application of electrically peaking hybrid (ELPH) propulsion system to a full-size passenger car with simulated design verification. *IEEE Transactions on Vehicular Technology*, *48*(6), 1779-1787.

[31] Gao, Y., & Ehsani, M. (2001). Electronic Braking System of EV And HEV-Integration of Regenerative Braking, Automatic Braking Force Control and ABS. *SAE transactions*, 576-582.

[32] Miller, J. M. (2004). *Propulsion systems for hybrid vehicles* (Vol. 45). Iet.

[33] Panagiotidis, M., Delagrammatikas, G., & Assanis, D. (2000). Development and use of a regenerative braking model for a parallel hybrid electric vehicle. *SAE transactions*, 1180-1191.

[34] Bobba, P. B., & Rajagopal, K. R. (2010, December). Compact regenerative braking scheme for a PM BLDC motor driven electric two-wheeler. In *2010 Joint International Conference on Power Electronics, Drives and Energy Systems & 2010 Power India* (pp. 1-5). IEEE.

[35] Qin, Y., Tang, X., Jia, T., Duan, Z., Zhang, J., Li, Y., & Zheng, L. (2020). Noise and vibration suppression in hybrid electric vehicles: State of the art and challenges. *Renewable and Sustainable Energy Reviews*, *124*, 109782.

[36] Li, W., Du, H., & Li, W. (2018). Driver intention based coordinate control of regenerative and plugging braking for electric vehicles with in-wheel PMSMs. *IET Intelligent Transport Systems*, *12*(10), 1300-1311.

[37] Zhang, J., Sun, W., Liu, Z., & Zeng, M. (2019). Comfort braking control for brake-by-wire vehicles. *Mechanical Systems and Signal Processing*, *133*, 106255.

[38] Yuan, Y., Zhang, J., Li, Y., & Li, C. (2018). A novel regenerative electrohydraulic brake system: Development and hardware-in-loop tests. *IEEE Transactions on Vehicular Technology*, *67*(12), 11440-11452.

[39] Zhang, S., Gao, K., Zhou, Y., Zhu, C., Xiao, Y., & Huang, Z. (2018, July). Regenerative braking control strategy of electric vehicle based on composite power supply. In *2018 37th Chinese Control Conference (CCC)* (pp. 7588-7593). IEEE.

[40] Junzhi, Z., Yutong, L., Chen, L., & Ye, Y. (2014). New regenerative braking control strategy for rear-driven electrified minivans. *Energy Conversion and Management*, *82*, 135-145.

[41] Nanda Kumar, C., & Subramanian, S. C. (2019). Brake force sharing to improve lateral stability while regenerative braking in a turn. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of automobile engineering*, *233*(3), 531-547.

[42] dos Santos Barros, T. A., dos Santos Neto, P. J., Nascimento Filho, P. S., Moreira, A. B., & Ruppert Filho, E. (2017). An approach for switched reluctance generator in a wind generation system with a wide range of operation speed. *IEEE Transactions on Power Electronics*, *32*(11), 8277-8292.

[43] Narla, S., Sozer, Y., & Husain, I. (2012). Switched reluctance generator controls for optimal power generation and battery charging. *IEEE Transactions on Industry Applications*, *48*(5), 1452-1459.

[44] Zhu, Y., Wu, H., & Zhang, J. (2020). Regenerative Braking Control Strategy for Electric Vehicles Based on Optimization of Switched Reluctance Generator Drive System. *IEEE Access*, *8*, 76671-76682.

[45] Kannan, K., & Sutha, S. (2010, June). PI-CCC based minimization of torque ripple in Switched Reluctance Generator using MATLAB/SIMULINK. In *2010 4th International Power Engineering and Optimization Conference (PEOCO)* (pp. 522-527). IEEE.

[46] Chuanwei, Z., Zhifeng, B., Binggang, C., & Jingcheng, L. (2004, August). Study on regenerative braking of electric vehicle. In *The 4th International Power Electronics and Motion Control Conference, 2004. IPEMC 2004.* (Vol. 2, pp. 836-839). IEEE.

[47] Saha, S., Dandekar, A. V., & Sundersingh, V. P. (1996). A modified approach of feeding regenerative energy to the mains. *IEEE Transactions on Industrial Electronics*, *43*(4), 510-514.

[48] Wicks, F., & Donnelly, K. (1997, July). Modeling regenerative braking and storage for vehicles. In *IECEC-97 Proceedings of the Thirty-Second Intersociety Energy Conversion Engineering Conference (Cat. No. 97CH6203)* (Vol. 3, pp. 2030-2035). IEEE.

[49] Han, J., & Park, Y. (2011). *Cooperative regenerative braking control strategy considering nonlinear tire characteristic in front-wheel-drive hybrid electric vehicle* (No. 2011-39-7209). SAE Technical Paper.

[50] Sandilya, D. K., Goswami, S., Kalita, B., & Chakraborty, S. (2017, June). A study on Regenerative braking system with matlab simulation. In *2017 International Conference on Intelligent Computing and Control (I2C2)* (pp. 1-6). IEEE.

[51] Lv, C., Zhang, J., Li, Y., & Yuan, Y. (2015). Novel control algorithm of braking energy regeneration system for an electric vehicle during safety–critical driving maneuvers. *Energy conversion and management*, *106*, 520-529.

[52] Lv, M., Chen, Z., Yang, Y., & Bi, J. (2017, October). Regenerative braking control strategy for a hybrid electric vehicle with rear axle electric drive. In *2017 Chinese Automation Congress (CAC)* (pp. 521-525). IEEE.

[53] Setiawan, J. D., Budiman, B. A., Haryanto, I., Munadi, M., Ariyanto, M., & Hidayat, M. A. (2019, November). The Effect of Vehicle Inertia on Regenerative Braking Systems of Pure Electric Vehicles. In *2019 6th International Conference on Electric Vehicular Technology (ICEVT)* (pp. 179-188). IEEE.

[54] Peng, D., Zhang, Y., Yin, C. L., & Zhang, J. W. (2008). Combined control of a regenerative braking and antilock braking system for hybrid electric vehicles. *International Journal of Automotive Technology*, *9*(6), 749-757.

[55] Yoong, M. K., Gan, Y. H., Gan, G. D., Leong, C. K., Phuan, Z. Y., Cheah, B. K., & Chew, K. W. (2010, November). Studies of regenerative braking in electric vehicle. In *2010 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology* (pp. 40-45). IEEE.

[56] Ehsani, M., Gao, Y., Longo, S., & Ebrahimi, K. (2018). *Modern electric, hybrid electric, and fuel cell vehicles*. CRC press.

[57] Morita, K. (2003). Automotive power source in 21st century. *JSAE review*, *24*(1), 3-7.

[58] Paganelli, G., Ercole, G., Brahma, A., Guezennec, Y., & Rizzoni, G. (2001). General supervisory control policy for the energy optimization of charge-sustaining hybrid electric vehicles. *JSAE review*, *22*(4), 511-518.