Integral Brake System for Electric Motorcycle Using Maximum Energy Regeneration

Integrales Bremssystem für elektrisches Motorrad mit maximaler Energieregeneration

Georgi Yanachkov*, Simona Hesapchieva†

* Department of internal combustion engines, automobiles and transport, Technical University of Sofia
Sofia, Bulgaria, *gyanachkov@tu-sofia.bg, †Simona_Hesapchieva@abv.bg

Abstract **—**This publication discusses the possibilities of regenerative braking of an electric motorcycle. The peculiarities of the construction of the motorcycle and the braking forces acting on it are discussed. The braking performance of the rear wheel has been examined and the brake force in which the maximum energy recovery rate is found. An integrated braking system model has been proposed to allow maximum energy recovery during braking.

Zusammenfassung **—** In der Artikel werden die Möglichkeiten des regenerativen Bremsens eines elektrischen Motorrads diskutiert. Die Besonderheiten der Konstruktion des Motorrads und der darauf wirkenden Bremskräfte werden diskutiert. Die Bremsleistung des Hinterrads wurde untersucht und die Bremskraft, bei der die maximale Energierückgewinnungsrate gefunden wird, ermittelt. Ein integriertes Bremssystemmodell wurde vorgeschlagen, um eine maximale Energierückgewinnung während des Bremsens zu ermöglichen.

I. Introduction

Electric vehicles are increasingly spreading. Their advantages over those equipped with ICE are that they do not pollute the environment, the electric motor has a higher efficiency, there is the possibility of reverse and stop-mode operation, higher acceleration, noise, lower cost per kilometer road.

The disadvantage is the low capacity of the batteries and their slow recharging. For this reason, energy regeneration systems have been developed in which the electric motor operates in a generator mode and the resulting electricity is used to power the on-board systems and to charge the battery. This extends the range and efficiency of the vehicle.

Motorcycles are characterized by a relatively high mass center and a short wheelbase, resulting in greater redistribution of the braking forces. As is known from the theory of the vehicle in braking mode, a torque is obtained that unloads the rear wheel. The shorter the base and the higher the center of the mass center, the greater the moment. In most motorcycles, there is a real danger of an intense braking momentum increasing to the extent that the rear wheel loses contact with the road before it reaches the adhesion limit. Exceptions are the heavy motorcycles with a long base.

Another feature of the motorcycle is that it is always with a rear wheel drive and only the braking force in it can be used to drive the electric motor in a generating mode for energy regeneration. Options for the deployment of a generator on the front wheel are not considered, this would increase the weight of the construction and lead to an increase in non-suspended masses in the suspension. This publication will examine how much of the total braking force can be achieved only with the rear wheel and, respectively, what part of the braking energy can be regenerated.

II. Forces acting on the motorcycle in braking mode and basic geometric parameters

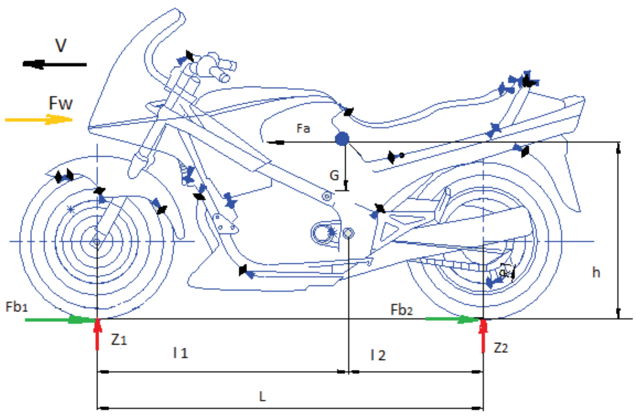

Fig. 1. Forces acting on the motorcycle in braking mode.

On the scheme on Fig. 1 are made the following indications [2]:

- Z_1 - normal front wheel reaction, N;
- Z_2 - normal rear wheel reaction, N;
- F_w – aerodynamic resistance force, N;
- F_{b1} - front wheel braking force, N;
- F_{b2} - rear wheel brake force, N;
- F_a - Inertial force, N;
- L - wheelbase of the motorcycle, mm;
- h - height of the center of gravity, mm;
- l_1, l_2 - coordinates of the mass center respectively by the front and rear axes, m
- G - mass of the motorcycle, N

III. Braking force in the rear wheel

To obtain how much of the braking energy can be regenerated, only the braking force applied to the rear wheel of the motorcycle is considered because it is connected to the electric motor. While braking the electric motor works as a generator.

The maximum braking deceleration achieved only with the rear brake is[1]:

$$a_{br.opt.} = \frac{\mu g . l_1}{\delta(L+\mu . h)} \qquad (1)$$

For greater braking deceleration, it is also necessary to activate the front brake. This results in an additional unloading of the rear wheel and lowering the corresponding braking force. This leads to a reduction of the percentage of regenerated energy relative to the total braking energy.

IV. Opportunities to recover the energy consumed when the rear wheel Brakes. Integral Brake System

In the case of low-intensity braking, it is possible to stop only with the rear wheel, which means that all braking energy can be restored as is shown in Fig.2.

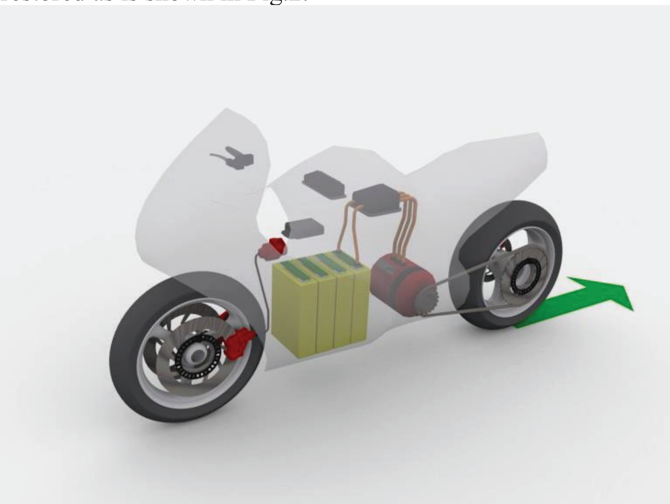

Fig. 2. Motorcycle braking with braking force applied only on the rear wheel.

For higher braking deceleration, it is also necessary to activate the front brake. Due to the progressive unloading of the rear axle, the braking effort on the rear wheel needs to be reduced Fig.3, otherwise the rear wheel will lose traction with the road, will slip and the motorcycle will lose stability.

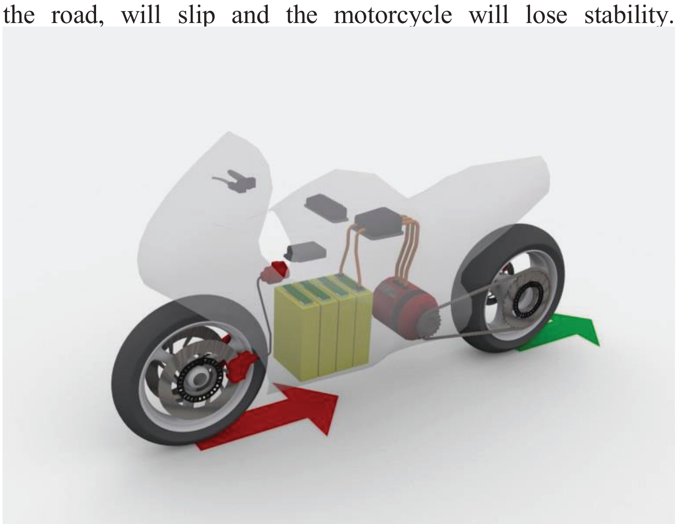

Fig. 3. Motorcycle braking with both wheels.

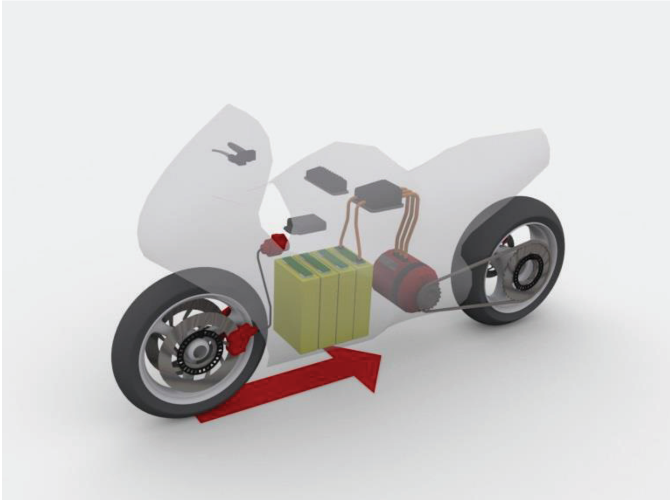

Fig. 4. Motorcycle braking with braking force applied only on the front wheel.

There is an extreme case of braking when the braking force in the front wheel is so great that lifts the rear wheel. In these case the motorcycle will lose contact with the road with his rear wheel and will flip over. That depends on the dimensions of the motorcycle – wheelbase and center of masses, and the traction coefficient [1]. The anti – flipover condition is:

$$\mu > \frac{l_1}{\delta\, h} \qquad (2)$$

The higher the center of masses and the shorter the wheelbase, the more prone to flip is the motorcycle. Especially vulnerable to that effect are the super-sport bikes and city scooters.

The exact law on the distribution of braking forces depends on the geometric and mass parameters of the particular motorcycle. To make a simple example the dimensions of Honda CBR1100 XX are used. This is a sport-touring motorcycle with widespread proportions. The dimensions are shown in Table I. The traction coefficient is $\mu = 0.8$ – something common for an asphalt road surface. The exact distribution law is shown in Fig. 2

TABLE I.

Design ation	Honda CBR 1100 XX		
	Parameter	***Value***	***Dimention***
L	Wheelbase	1450	mm
l_1	Coordinates of the mass center respectively from the front wheel.	725	mm
L_2	Coordinates of the mass center respectively from the rear wheel.	725	mm
h	Height of the center of masses.	800	mm
G	Mass of motorcycle	330	Kg

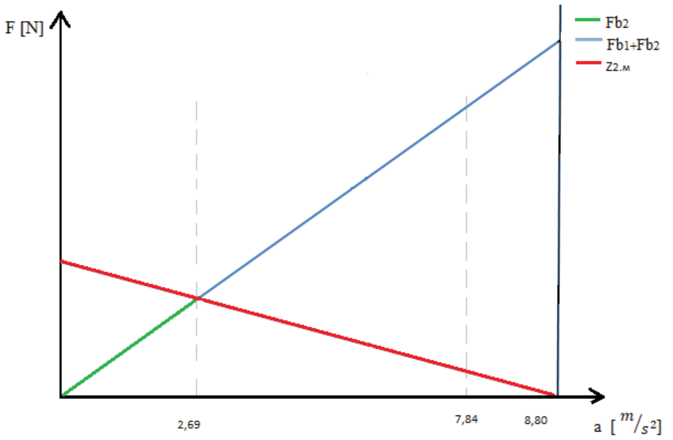

Fig. 5. Proportional distribution of braking forces between front and rear wheels depending on braking deceleration.

As seen on the figure in the area of brake decelerations below 2,69 m/s^2 it is possible to stop only with the rear wheel. In that case all of the braking force can be transferred to the motor/generator and be converted to energy. The maximum deceleration is 7.84 m/s^2. If the traction coefficient was higher, then the motorcycle can brake more intense until the deceleration is 8.80 m/s^2. By that time the braking force is so high that the rear wheel loses traction and the motorcycle flips over. For the current calculations, the coefficient of the rotating masses, the rolling resistance and the air resistance are not taken into account.

To achieve the optimum distribution of braking forces between the wheels an Integral Brake System is needed.

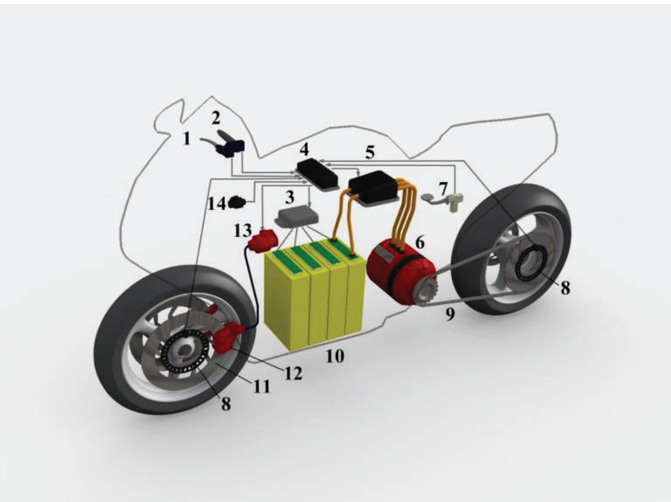

Fig. 6. Basic schematic view of an Integral Brake System optimized for maximum energy regeneration.

The Integral Brake System consists of following elements as shown on Fig. 6:

1 - Brake lever;
2 - Throttle;
3 - Battery Management System;
4 - Boardcomputer;
5 - Controller;
6 - Electric motor;
7 - Brake pedal;
8 - ABS sensor:
9 - Final drive;
10 - Battery pack;
11 - Front brake disk;
12 - Front brake caliper;
13 - Hydrocylinder;
14 - Braking deceleration sensor;

The main control instrument of the system is the hand brake lever. The input value is the brake handle position and its corresponding brake deceleration. The relation between them can be linear or nonlinear, depending on the rider preferences. Other source of input value can be the foot brake pedal. The brake handle sends signal to the boardcomputer and commands to the motor controller. The controller is connected to the battery pack and it's battery management system. For applying brake force to the front wheel is used the standard brake disk and caliper. The only difference is that the brake is not directly controlled by the handle, but through an electrohydraulic cylinder, controlled by the boardcomputer. The ABS sensors for the front and the rear wheel are also connected to the boardcomputer. Information for the intensity of the braking is given by a braking deceleration sensor. The system can be further complicated by other sensors – for leaningin the corners, tyre condition, weather condition, etc.

The simplified diagram of the functioning system is shown on Fig.7.

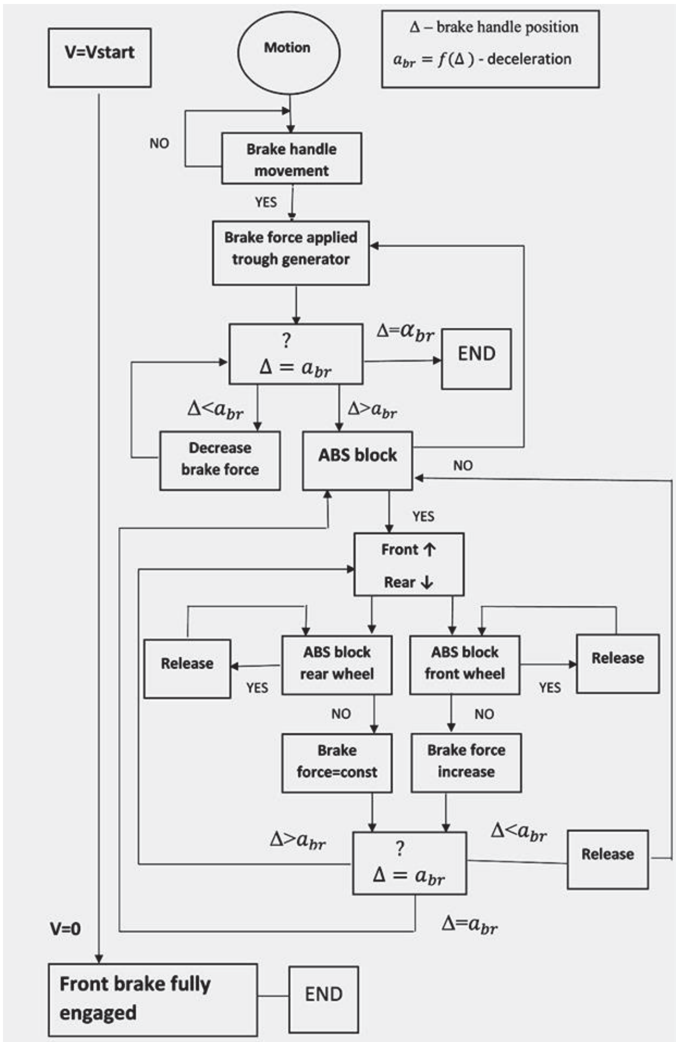

Fig. 7. Block diagram of the function of an Integral Brake System optimized for maximum energy regeneration.

The main parameters of the control logic are the brake handle position **Δ** and the brake deceleration $\mathbf{a_{br}}$. The braking process begins in certain speed. Than the brake lever is actuated. That gives a signal to the controller to switch the electric motor in generator regime at minimum resistance. The computer checks if the brake deceleration corresponds with the brake handle position and if there are differences increases or decreases the braking force (generators resistance). There are constant ABS-checks for locking the rear wheel and if a lock is detected then the front wheel brake is engaged and the brake force in the rear wheel is decreased. From that point on there is a big logic cycle for balancing the forces so the rear wheel is always on the edge of blocking and the rest of the needed braking force is achieved with the front brake. When the speed decreases to a stop the front brake is fully engaged the vehicle stands still and the whole braking process ends.

When the rider releases the brake lever the front brake disengages, the electric motor is back to traction regime and the motorcycle is ready to accelerate again.

CONCLUSIONS

It is possible to use the rear brake only and therefore all the energy consumed during braking to regenerate until a certain braking delay.

When the braking delay increases, the percentage of recovered energy decreases.

Greater opportunity for regeneration of energy is found in motorcycles with a longer base and a lower center of gravity.

The above dependencies can be used to program an integral braking system with maximum use of the braking power to charge the battery of an electric motorcycle

REFERENCES

[1] G. Yanachkov, S. Hesapchieva, "Regenerative braking possibilities of an electric motorcycle," *Bultrans 2018,* Sozopol, October 2018.

[2] D. Semov, N. Ivanov, D. Lozanov, *Automobiles, tractors and forklift trucks*, Tehnika, Sofia, 1992.

[3] S. Dimitrov, *Theory of the automobile*, Technical University - Sofia, Sofia, 2016.

[4] K. Kosev, L. Kunchev, *Motorcycles, sport- and racecars*, Technical University - Sofia, Sofia, 2010.

[5] N. Djagarov, *Electric drive*, Technical University - Varna, 2011.

[6] M.Minchev, J. Shopov, E. Rac, *Conversion technology*, Avangard Prima, Sofia, 2006.