THE MOTORCYCLE INTEGRAL BRAKE SYSTEM MIB – AN ADVANCED BRAKE SOLUTION FOR HIGH PERFORMANCE MOTORCYCLES

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ABSTRACT

Brake systems for motorcycles are available in many different designs with different technical solutions. Beginning with a conventional brake system with two independent circuits, an ABS system can be added to improve safety and stability. A combined brake system can be created to enhance safety and comfort by establishing a hydraulic connection between the front brake control and the rear caliper or vice versa.

The Motorcycle Integral Brake System MIB, which was introduced to the market in 2006, provides motorcycle manufacturers with the possibility to realize any combined integral functionality characteristic. In addition, the pressure in each brake circuit can be built up actively independently of any rider input, so that the system reacts appropriately in any riding situation. Integral brake functions can be adapted to the philosophy of the motorcycle manufacturer, and many additional functions which were impossible until now can be incorporated.

This paper describes the Motorcycle Integral Brake system, its operating principles compared with other brake systems, and its various hydraulic and functional possibilities.

INTRODUCTION

Motorcycle brake systems are in a constant state of technical development. The driving force behind this development is the end consumer's desire for continuous improvements in comfort, riding pleasure and safety.

Increasing comfort means, on the one hand, development of brake systems in which slight corrections in speed can be achieved by applying minor forces to the hand brake lever. Here, the hand lever feeling should correspond with the feeling of deceleration and should reflect the deceleration performance.

Moreover, comfort is also increased by additional functions that can be realized with the brake system or in connection with other motorcycle systems. These include, for example, brake systems that effectively prevent rolling-back when starting on inclines, or allow comfortable starting on inclines without the need for the rider to balance the motorcycle with the throttle and brake.

Riding pleasure with regard to the basic brake system means direct response of the brake with a characteristic for the hand brake lever braking effect and deceleration that is adapted to the motorcycle characteristics. The rider expects a direct reaction of the motorcycle to his wish to brake.

Besides this, additional functions can also increase riding pleasure. These include functions that increase comfort (see above), as well as functions that reduce the number of actuating elements required to achieve a braking effect corresponding to the riding situation. Generally, however, riding pleasure means evoking emotions when riding, emotions which make the overall riding experience enjoyable.

The desire for safety is paramount with motorcycles, even more so than with cars, since the consequences can be much more grave if a critical riding situation arises and a fall results. Even if the (possibly even subconscious or repressed) willingness of motorcycle riders to take a risk is greater than that of car drivers, the number of traffic deaths is the subject of increasing public criticism. The percentage of motorcycle traffic deaths among the total number of traffic deaths is comparatively high when the number of miles driven is taken into consideration. As a result, the active and passive safety of motorcycle riders must be continuously improved in the future as well. Here, ABS will increase in significance, since this system is capable of maintaining the stability of the vehicle, thus preventing a fall and an uncontrolled collision of a motorcycle rider with an obstacle. Maintaining stability is, therefore, the primary goal. Even if a collision cannot be avoided, ABS reduces the energy of the impact and provides a more favorable position for a collision since the rider remains sitting upright.

It is also important to achieve short braking distances, since reduction of the collision speed can also lessen the consequences of an accident, and this is also supported by such a system.

The operating principles of brake systems and the functional possibilities of various design forms are described below in order to show the resultant requirements and possibilities from a technical point of view.

System Principles of Motorcycle ABS Brake Systems

<u>Hydraulic Brake Systems</u> - The system principles of motorcycle brake systems can also be understood as describing the evolution of these systems. Beginning with a 2-circuit brake system (Figure 1), in which the rider creates hydraulic pressure, for example by depressing a hand brake lever, which is transferred to the front wheel brake via hydraulic lines, and is then converted into braking force applied to the wheel. The same applies to actuation of the foot brake lever (or second hand brake lever). Nowadays, disk brakes are primarily used in brake systems. Such brake systems are technically sophisticated and are employed in a variety of ways, but without additional measures they do not live up to the requirements placed on modern brake systems for motorcycles with regard to the avoidance of wheel lockup. The rider must self modulate the pressure in the brake system in order to achieve a short braking distance. This means that build up of braking pressure at the front wheel must be as quickly as possible in accordance with the ideal braking force distribution, without causing the wheel to lock up. At the same time, braking pressure must also be built up as quickly as possible on the rear wheel, but must also be reduced again during braking due to the dynamic shift in the center of gravity.

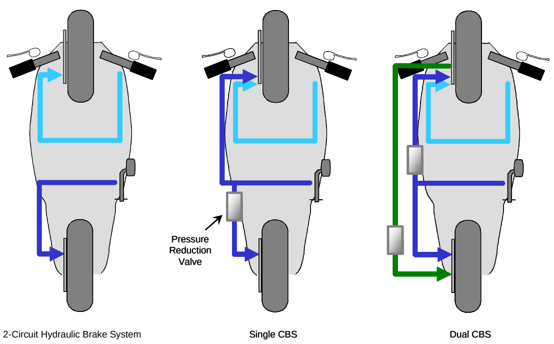

Figure 1. Principles of Hydraulic Brake Systems.

This is the only behavior that ensures a short braking distance while simultaneously maintaining the stability of the motorcycle.
In general, however, a motorcycle rider is completely overtaxed by such a requirement, especially in emergency situations. This either leads to the vehicle not being decelerated ideally (the pressure build-up is either too weak, too late or too low), or the wheels are over-braked, i.e. they lock up, which by definition endangers the stability of the vehicle and usually leads to a fall.
In order to ensure nearly ideal brake force distribution between the front and rear wheels, motorcycles are available on the market with so-called CBS systems (Combined Brake Systems). These systems are available in 2 versions:

- Single CBS, in which the hand control acts on the front wheel and the foot control (or the second hand control) acts on the front and rear wheels. This allows relatively high rates of deceleration to be achieved by actuating only one of the control elements.
- Dual CBS, in which both wheels are braked by actuation of the hand and foot brake levers.

The hydraulics of such systems are relatively complex, since a floating front caliper with an additionally connected actuating cylinder (so-called secondary cylinder) is required in both systems. This is responsible for pressure build-up on the rear wheel. However, this configuration also requires an additional hydraulic connection from the front wheel caliper to the rear wheel caliper. In addition, the front wheel caliper is divided hydraulically (e.g. 5 pistons connected with the hand control, 1 piston connected with the foot brake), which also has a decisive influence on the cost of the overall system.
Pressure limitation on the front and rear wheels in accordance with a desired brake force distribution is achieved by augmenting these brake systems by pressure limiters or brake force control valves.

<u>Hydraulic ABS Brake Systems</u> - Preventing wheel lockup and thus maintaining stability can be ensured only by a system that actively modulates the brake pressure, i.e. a system which reduces the braking pressure in certain situations, so that the wheel can be released to accelerate again if a lockup threatens, thereby maintaining lateral stability. Such anti-lock brake systems (ABS) have been available for passenger cars since their introduction in 1978. Since then, they are considered a key element in active safety, the mandatory ACEA self-commitment for new cars on the European market to have ABS has take an effect since 2004.
The first motorcycle ABS system was introduced in 1988 on a BMW K100LT, and it has been gaining recognition in the motorcycle segment since then. It is an undisputed fact that preventing lockup of the wheels ensures the stability of the vehicle, thus significantly reducing the consequences of accidents or preventing them in the first place.
In a dual-circuit brake system (Figure 2), the ABS is positioned between the control and the wheel brake. It detects the motion of the wheels in each hydraulic circuit via wheel speed sensors. The system recognizes if the rotational speed drops disproportionately quickly during a braking operation, and the braking pressure is reduced again via valve outlet action.

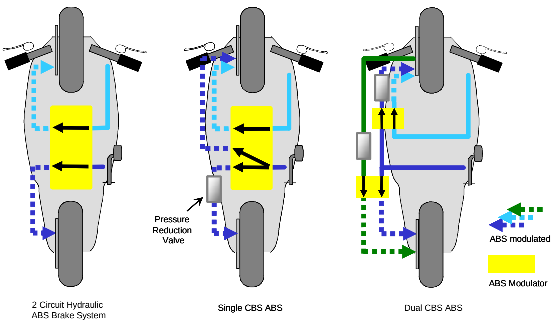

Figure 2. Principles of ABS Brake Systems.

When the wheel has nearly reached the reference speed of the vehicle again, the braking pressure is increased once more in order to continue decelerating the vehicle.
The principle is similar for a single CBS-ABS system, except that there is an additional modulator circuit on the front wheel due to the connection of the rear wheel control. Such systems require a total of 3 control channels which can be regulated independently of one another.
Dual CBS-ABS is characterized by the fact that the dual CBS brake system mentioned above is supplemented by ABS modulators. Here, a total of 4 control channels are needed, since one channel is required in each case for regulating the brake pressure from the hand lever to the front wheel, from the foot brake to the front wheel and to rear wheel, and from the secondary cylinder on the front wheel to the rear wheel.
In addition, there are also systems on the market that have an integrated boost function for the CBS-ABS function. These systems are designed to reduce the actuation force in order to increase comfort when braking. In this case, the hydraulic circuits of the operating elements are separated from the wheel brakes. A hydraulic pump is activated for each actuation, even in the case of partial braking, so that pressure can be built up in the wheel brake cylinder.

Electro hydraulic Integral Brake Systems - Pure ABS systems are operated passively, since they cannot build up braking pressure autonomously. However, systems are known from the automotive sector that are capable of building up pressure on the individual wheels actively.
Such systems are used for Electronic Stability Control (ESC). This principle is utilized for motorcycles in developing electronic integral brake systems. Like single CBS systems, the devices can initially be systems that build up pressure on the front wheel brake when the rider actuates the foot control lever. This is a partial integral brake system which acts in forward direction. Analogously, a partial integral system acting to the rear can also be implemented, where pressure is applied to the rear wheel via an electrically controlled pump each time the hand brake lever is actuated.

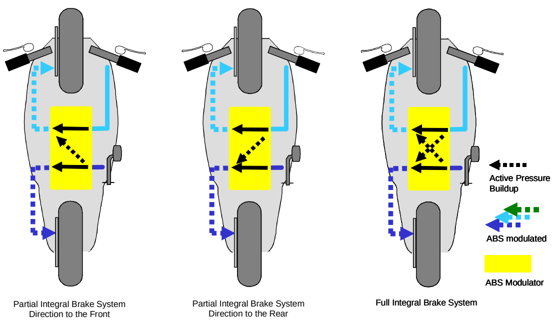

Figure 3. Principles of Electronic Integral Brake Systems.

If the brakes are always applied to both wheels when a brake control is actuated, this is called a full integral brake system. The design principle of this system means that it is capable of actively building up pressure on both wheels. As a result, several additional functions can be realized for applying pressure to the brakes depending on the riding situation, as well as in conjunction with other control devices.
The 2-channel ABS system, rear-acting partial integral brake system, and full integral brake systems are described in detail below.

Functional Potential of Different Brake Systems - The categorization mentioned in the introduction according to comfort, riding pleasure and safety can be used to outline the possibilities of the respective brake systems (Figure 4). This categorization is, however, heavily dependent on the vehicle or type of rider. A cruiser rider will most certainly evaluate comfort criteria differently than the rider of a sports machine. In addition, the details are also dependent on the philosophy of each individual motorcycle manufacturer. Nonetheless, an attempt will be made here to evaluate the above-mentioned systems generally with regard to riding comfort and pleasure and especially to safety.

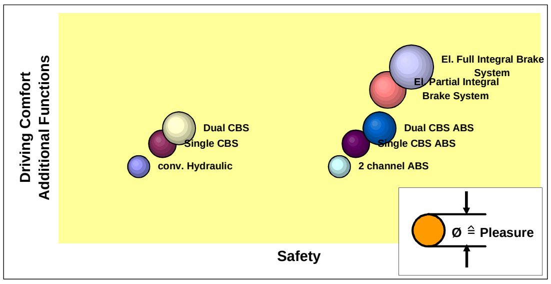

Figure 4. Potential of Different Brake Systems.

Based on conventional hydraulics, increased riding safety initially means greater deceleration when both wheels are braked by operation of control, or a reduction in the tendency of a wheel to lock up for a given deceleration. The wheel lockup tendency is reduced by way of the predefined brake force distribution. This was essentially achieved with the introduction of the CBS systems.

Brake systems experienced a large increase in safety with the introduction of 2-channel ABS systems. These systems significantly improve the stability of the motorcycle during a braking operation and reduce the frequency of falls. As with the CBS systems without ABS, the safety potential is increased via the fixed, preset brake force distribution of the CBS systems. Electronic integral brake systems are able to shorten the braking distance once again thanks to the electric brake force distribution, which also means an increase in safety.

Riding comfort can be improved, for example, through use of hydraulic integral brake systems such as CBS. High deceleration is achieved by actuation of a control and, depending on the system, pitching is reduced at the same time. If additional functions are counted towards riding comfort, electronic integral brake systems allow functions to be implemented that make operation easier for the rider. Several of these additional functions will be described below.

Riding pleasure is the variable that is most difficult to define, and it is the one that is most dependent on the personal preferences of a motorcycle rider or the manufacturer's philosophy. It is primarily associated with emotions that the motorcycle rider experiences. In terms of the basic brake, this corresponds to a brake that responds directly with a clearly reproducible pressure point on the hand brake lever and therefore reflects the deceleration characteristic. This was positively influenced by the introduction of CBS and CBS-ABS systems, since pitching of the motorcycle is reduced and relatively high deceleration can be achieved with pressure build-up at one control.

With the aid of the electronic integral brake system, however, the functions can also be adapted to the specific requirements of motorcycle manufacturers and the end customer in much greater detail, thus also increasing riding pleasure.

Functional Principles of Electro hydraulic Brake Systems with Valve Control

2-Channel ABS System - In this HECU (Hydraulic-Electronic Control Unit), two valves (an inlet valve and an outlet valve) per wheel circuit are responsible for modulation of the braking pressure at the wheel (Figure 5).

If ABS is activated, the inlet valve ensures that the actuating cylinder is hydraulically separated from the wheel brake. The outlet valve is opened in order to allow the hydraulic volume in the wheel brake to escape into the low pressure accumulator, thus reducing the braking force and allowing the wheel to reaccelerate. Once the wheel has reached the reference speed of the vehicle again, the outlet valve is closed and the inlet valve is reopened, so that the rider can again build up brake pressure at the wheel.

A hydraulic pump sucks the hydraulic volume out of the low pressure accumulator and feeds the actuating cylinder. The rider perceives the continuous build up and release of pressure as pulsation in the controls, informing him that ABS is active. The rider therefore is aware that he is at the brake-slip threshold.

The inlet valve is designed in such a manner that it is open in de-energized state, i.e. the hydraulic pressure is directed towards the brake. The outlet valve is closed when de-energized. If the ECU fails, the hydraulic pressure of the brake cylinder is therefore routed directly to the wheel brake, and the rider is notified of this by a warning lamp in the cockpit display.

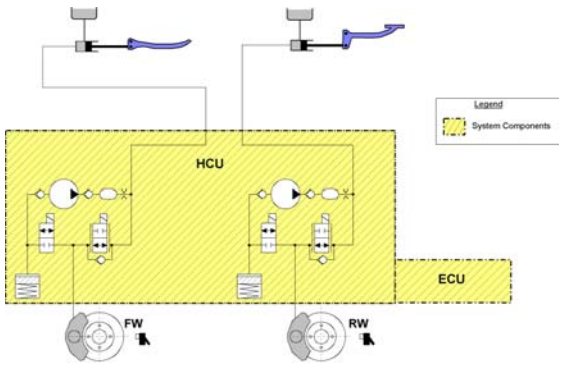

Figure 5. Motorcycle Anti-lock Brake System (MAB) System Diagram.

Rotation of the wheels is detected by wheel speed sensors on the front and rear wheels. In addition, the ECU is connected to the on-board 12 V supply, in order to provide the HECU with the required power. The ECU may also control cockpit warning lamps. Connection to the CAN network is possible in order to communicate the status of the ABS system, internal signals or other dynamic riding variables to other control devices.

MIB MK 1-3 Partial Integral Brake System - In addition to the functionality of a pure ABS system, an integral brake system can actively build up braking pressure on the wheels without the rider having to operate the corresponding controls (Figure 6).

A special design variant is the partial integral brake system, in which the braking pressure is actively built up at the rear only. This means that an integral function is realized from the hand brake lever to the rear wheel with such a system.

A partial integral brake system consists in total of 6 hydraulic valves, two for the front wheel circuit, four for the rear wheel circuit, 3 pressure sensors, one low pressure accumulator and one hydraulic pump per wheel circuit and an ECU (Electronic

Control Unit). The two pumps of each wheel circuit are both driven by an electric motor.

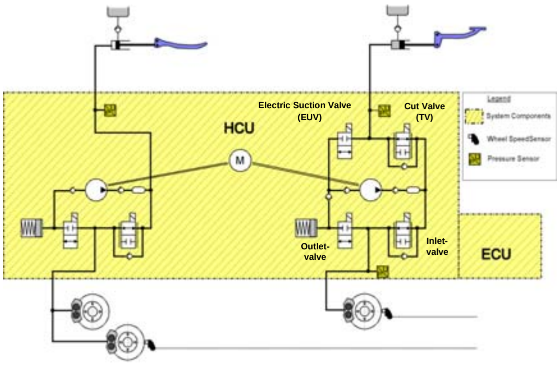

Figure 6. Motorcycle Integral Brake System (MIB) Partial Integral Brake Function.

If the rider actuates the hand brake lever, the pressure is hydraulically applied to the front wheel brake. At the same time, the pressure sensor measures the pressure increase and sends this information to the ECU. The pump motor is controlled in accordance with preset characteristics, operating modes or other characteristic variables. To actively build up pressure at the rear wheel, the cut valve (TV-HR) is closed and the suction valve (EUV-HR) is opened. Then the pump sucks brake fluid out of the reservoir and builds up pressure in the rear brake caliper.
If the rider additionally activates the foot brake lever, the suction valve is closed once again the wheel braking pressure is attained, and the cut valve is reopened, so that the rider has direct intervention from the foot pedal to the rear wheel brake once more.
The transitions represent a particular challenge in this respect. The goal is to design the transitions in such a manner that the rider hardly perceives any feedback in the foot lever. This is possible with a balanced design of the hydraulics and the control software.
The front wheel circuit is designed as an ABS circuit with regard to the valve configuration. Only the pressure of the front wheel is modulated if the front wheel threatens to lock up during a braking operation.
Three solenoid valves (inlet valves on the front and rear wheels and block valve on the rear wheel) are designed as analog valves in order to achieve highly precise pressure modulation. This leads to exact adjustment of the pressure at the wheels and also to a reduction in the force feedback at the controls, thereby significantly improving comfort.

<u>**MIB MK 1-4 Full Integral Brake System**</u> **-** In addition to the functionality of the partial integral brake system (which acts to the rear), the full integral brake system also offers the possibility of actively building up pressure at the front wheel. This is realized by using two additional solenoid valves and a pressure sensor to complement the front wheel circuit (Figure 7).

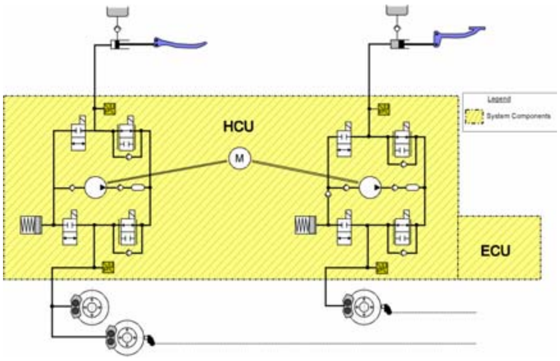

Figure 7. Motorcycle Integral Brake System (MIB) Full Integral Brake Function.

The functionality is similar to that of the partial integral brake system, except that additionally the rider input is also measured at the rear wheel control. Braking pressure can also be built up at the front wheel corresponding to the riding conditions and desired function.
The possibilities of realizing additional functions with such systems are described below.

Overview of the Most Important Functions

The functional basis of the motorcycle integral brake system is the anti-lock function of the ABS system (Figure 8). The goal of this safety function is to maximize utilization of the friction coefficient potential between the motorcycle tire and the road in order to prevent lockup. Especially with motorcycles, a front wheel lockup of more than several hundred milliseconds with the resultant loss of stability and a subsequent fall can have fatal consequences.

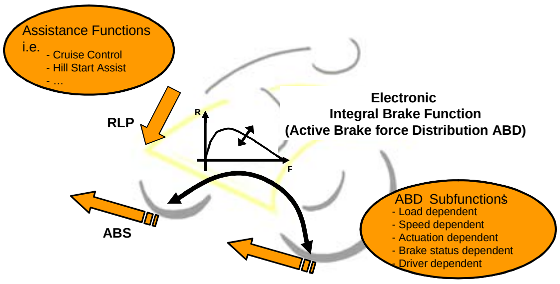

Figure 8. Motorcycle Integral Brake System (MIB) Function Overview.

Rear Wheel Lift-Off Protection (RLP) is indispensable for most motorcycles as a functional supplement to ABS for the vertical dynamics of the motorcycle. Here, the goal is to ensure a stabilizing remaining load for the rear wheel in order to prevent a flip. The heart of the MIB system is the electronic integral braking function with Active Brake force Distribution (ABD) for distributing the rider's braking command to the basic brakes at the front and rear. In the case of the partial integral brake, active brake pressure generation can be functionally applied at the rear wheel due to the hand lever being actuated (ABD front to rear) or the brake pressure can be adjusted at the front wheel due to the foot lever being actuated (ABD rear to front). The full integral brake system incorporates both partial functions. Overall, ADB is variable depending on the load, vehicle speed, actuation characteristics and the two actuating controls.

There is also the possibility of providing adjustment options for the individual rider.

Assistant functionalities can be integrated thanks to the possibility of changing or generating brake pressure in an interaction with the motorcycle rider. Cruise control including brake intervention and hill start assist are only a few examples of such functions.

Rear Wheel Lift-Off Protection (RLP) - When the brakes are fully applied, there is a major dynamic wheel load displacement from the rear to the front wheel. Depending on the motorcycle design or the rider position, the rear wheel may lift off as a result (Figure 9).

Figure 9. Motorcycle Integral Brake System (MIB) Rear wheel Lift-off Protection.

The loss of wheel contact force on the rear wheel not only results in an early lockup tendency, but also very imprecise handling of the motorcycle when braking. Experienced riders compensate for this by removing braking pressure from the front wheel or performing a "stoppie".

However, there is a high risk of a flip in the case of a rapidly executed panic stop with the associated high dynamic forces acting around the transversal axis. RLP prevents this, thus taking the fear of fully applying the brakes from the rider.

RLP compares the wheel speed signals and the derived signals of both wheels during the braking operation. In addition, the pressure information of the individual control circuits is processed to determine a lift-off tendency. The pressure control algorithm of the front wheel reduces the braking pressure below the ABS limit in such a way that a minimum wheel contact force is maintained. This eliminates the risk of a flip while simultaneously maintaining ideal deceleration.

Active Brake force Distribution (ABD) - ADB is responsible for the appropriate distribution of the rider's braking command to both wheels. This is carried out in interaction with the brake pressure directly applied by the rider hydraulically via the two actuating controls, whereby the individual distributions, from the hand lever to the rear wheel and from the foot lever to the front wheel are realized using software (Figure 10).

The basic characteristic can be based on the ideal braking force distribution and then adapted to suit the situation. Here, input variables such as vehicle speed, as well as signals that describe the rider braking profile are used. This means, for example, that the influence of the rear wheel brake can be reduced at very low speeds in order to achieve ideal handling.

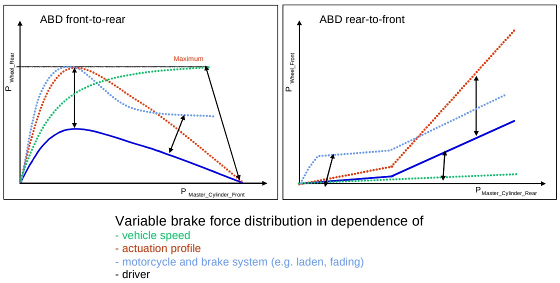

Figure 10. Motorcycle Integral Brake System (MIB), Active Brake force Distribution (ABD).

Additional possibilities for influencing the brake force distribution are the detected load change and brake state changes such as fading. The rider is also provided with the possibility of customizing the motorcycle by switching between different modes using preset tuning options.

Hill Start Assist (HSA) - The rider is required to perform complex operations using a wide variety of operating controls particularly when stopping and starting on steep gradients or off-road. The stopping operation is made more difficult in situations where locking the front wheel with the hand lever is not sufficient to prevent the motorcycle from rolling/sliding away due to the incline. Here, the foot brake also needs to be used.

With MIB it is possible to significantly relieve the rider's workload for operation of motorcycle via the HSA function. The system assists the rider in stopping and starting, so he can concentrate on more important, higher priority tasks.

If the rider brings the motorcycle to a stop on an uphill slope, the HSA function freezes the required brake pressure at the wheels (Figure 11). The hydraulic configurations of a partial integral brake suffice for this, while the full integral brake offers the most comprehensive set of options.

The rider can now release the brake controls and observe the surrounding traffic, and MIB keeps the motorcycle stationary on the incline. All that is needed to start is the application of the clutch and throttle. Enough residual pressure remains in the brakes to prevent roll-back as long as the engine power is insufficient for safe acceleration.

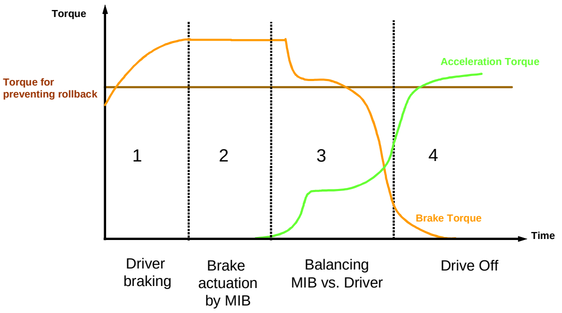

Figure 11. Motorcycle Integral Brake System (MIB) Hill Start Assist (HSA).

CONCLUSION

With MIB, the necessary basis has been created for integrating additional safety functions beyond the basic functions of ABS and RLP, and for improving the performance of the existing functionality. A variety of assistant functions will continue to relieve the rider, as in passenger cars, and increase riding safety in the future. First examples have already demonstrated this.

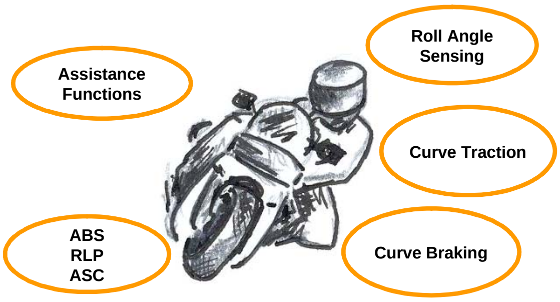

Figure 12. Motorcycle Integral Brake System (MIB) Outlook.

Additionally, sensitive sensors that better describe the riding dynamics of motorcycles extend the possibilities for safe use of traction control systems (Figure 12). Here too, the first steps towards enhanced safety in cornering situations have recently been taken by integrating the information from roll angle sensors into the control systems.

REFERENCES

Hoffman, O., Eckert, A., Woywod, J. “The Motorcycle Integral Brakesystem MIB: an advanced brake solution for high performance motorcycles”, 6. Internationale Motorradkonferenz, Köln, 9.-10.10.2006