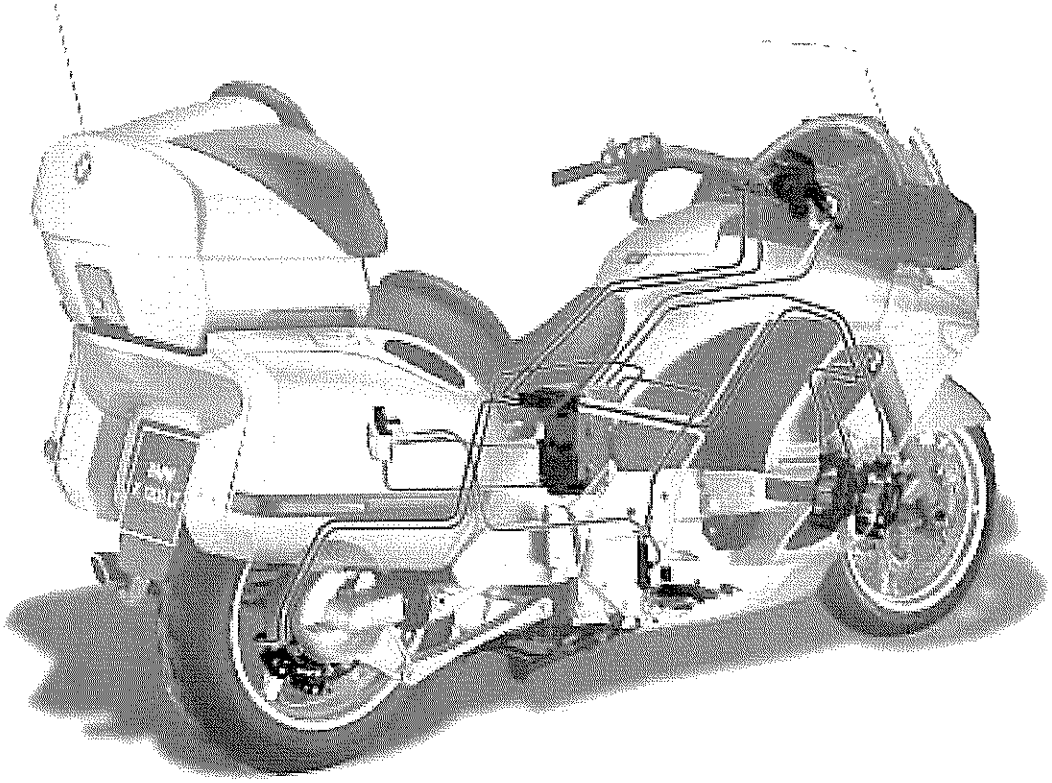
New Integral ABS from BMW Motorrad



By Markus Braunsperger, Siegfried Beulich and Hans-Albert Wagner

Twelve years after the presentation of the first anti-lock brake system for motorcycles, BMW Motorrad is now once again introducing a new brake system.

Developed by BMW in cooperation with FTE automotive GmbH, the new Integral ABS sets new standards in the area of brake technology and, accordingly, active safety in riding a motorcycle.

Apart from the further refined ABS control function, this system offers the usual combination of front and rear-wheel brake operation otherwise found on passenger cars and, for the first time, features an electrohydraulic brake servo as well as adaptive brake force distribution.

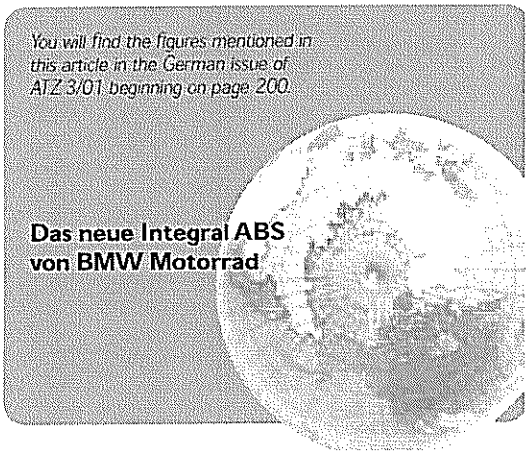
1 Introduction

In terms of the technical performance of brake systems, the running gear and tyres, the development of motorcycles has by all means kept up with the increase in engine output and road speed in the course of the last 10 years. When the brakes are applied in an emergency, however, the question is not only "what is the brake system able to offer?", but also – and this is the decisive point – "to what extent is the rider in a position, when applying the brakes in an emergency, to capitalise in full on the technical potentials offered by the brake system?"

When applying the brakes on a single-track vehicle, not even the experienced rider will be able to capitalise on the maximum brake power available when acting in a state of shock [1]. Accordingly, average use of the maximum stopping power available is only 58%. Only real specialists such as test or racing riders are able to apply the brakes smoothly and simultaneously on both the front and rear wheel with the considerable change in wheel load caused by the dynamic load shift when braking.

Situations in which the rider, due to lack of experience, fails to operate the brakes in full and thus gives up crucial stopping distance are just as relevant. There can be no doubt, therefore, that the human being is

You will find the figures mentioned in this article in the German issue of ATZ 3/01 beginning on page 200.



the "weak point", as it were, in the brake system and that ABS technology is superior to even the best rider when applying the brakes in full, especially on rapidly changing road surfaces with sudden jumps in the frictional coefficient, for example on wet roads, slippery stretches of tar, gravel or dirty surfaces, **Figure 1** [2].

BMW was the first motorcycle manufacturer in the world to introduce an electrohydraulic anti-lock brake system in spring 1988, immediately becoming a success in the market. This initial system was followed in spring 1993 by the low-weight second-generation ABS II. More than 250,000 customers have opted so far for a BMW motorcycle with ABS, proving that choosing the "right motorcycle" involves a high standard of safety awareness and not, as is often assumed, the simple wish for optimum acceleration and a very high top speed. The fact nevertheless remains that even ABS cannot override certain laws of physics. Whether with or without ABS, for example, the options to apply the brakes in a bend with the motorcycle leaning over at an angle are clearly limited.

BMW's new Integral ABS uses all technical possibilities available today to support the rider to the greatest possible extent, ensuring the shortest possible stopping distance under all circumstances when the brakes are applied in an emergency.

2 BMW Integral ABS at a Glance

The development of BMW's new Integral ABS was based on the following objectives:
- to ensure a further reduction in stopping distances
- to significantly reduce the brake operating forces
- to come as close as possible to the ideal brake force distribution on the front and rear-wheel brakes
- to take different load conditions into account
- to reduce the weight of the system
- to enhance the system's self-supervision/self-diagnosis functions

BMW's new Integral ABS uses the technical potentials of the new, further developed third generation of ABS, combining these features with various additional functions:

Integral Brake System
Both the handbrake and footbrake lever act simultaneously on both the front and rear-wheel brakes.

Adaptive Brake Force Distribution
Brake force at the rear wheel is controlled by a self-learning, electronic brake force distribution system.

Brake Servo
This is a new, electrohydraulic system.

BMW Integral ABS also marks the debut of the EVO (evolution) front-wheel brake, which offers up to 20% more braking power under the same manual force exerted by the rider with his hand.

In terms of its technical structure, BMW's Integral ABS is an almost completely new design without any components from former ABS units. All the control electronics and electrohydraulic components are housed in one single element, the pressure modulator. With the exception of the sensor rings and sensors on the wheels, Integral ABS is made up of the same structural elements as a conventional brake system without ABS, that is, the brake callipers, the main brake cylinder and the hydraulic lines, **Figure 2**. Although BMW Integral ABS has a much wider range of functions and significantly enhanced performance features versus ABS II, it is more than 20% lighter, with an overall weight of just 4.36 kg.

The core elements of BMW Integral ABS are the two control valves, one each for the front and rear-wheel brake system. These control valves separate the overall brake circuit into one circuit between the main brake cylinder and the control valve and an additional wheel circuit between the control valve and the brake calliper, **Figure 3**.
BMW's new Integral ABS comes in two different versions: the fully integral and the partly integral version. On the fully integral version featured initially in the BMW K 1200 LT, Cover Figure, both the handbrake lever and the footbrake lever act simultaneously on the front wheel and rear wheel brakes, **Figure 4**.

The reason is that many motorcycle riders now switch over directly from their car to a motorcycle and do not have the many years of motorcycling experience riders often had in the past. When applying the brakes in an emergency, such riders often only apply the footbrake and thus give away far more than 50% of the braking power potential.

While the rider was formerly required to operate the hand-brake and footbrake in full when applying the ABS brakes in order to build up maximum stopping power on the front and rear wheel with ABS operating at the wheel slip limit, BMW's new fully integral ABS only requires operation of either the footbrake or handbrake. **Figure 5** shows the extra safety provided by this combination of front-wheel and rear-wheel brake application when operating only the footbrake.

On the partly integral version, the handbrake lever acts on the front-wheel and rear-wheel brakes together, with the footbrake lever acting only on the rear wheel brake. This variant is particularly useful for the sports rider who brakes the rear wheel during a bend in order to stabilise the motorcycle.

3 Operation and Action of BMW Integral ABS

Whenever the rider applies the brakes all-out, regardless of whether he is applying the front or rear-wheel brake, each wheel is slowed down to the greatest possible extent, depending on the road surface friction. To perform this control function, the system changes the brake pressure.

Since it features lighter mechanical components and, as a result, requires a lower level of activation energy and power uptake, BMW's new ABS is able to reduce brake pressure even more quickly whenever there is a risk of the wheel(s) locking. Compared with the second-generation ABS II, BMW's new Integral ABS requires only 80 instead of 90 - 103 ms for this purpose.

On a homogeneous surface with the frictional coefficient remaining consistent, it is not sensible to build up or reduce pressure even more quickly during operation of the ABS system, since the wheels are unable to respond even more quickly to changes in pressure due to their mass inertia – although integral ABS would by all means be in a position to modify the level of pressure more quickly. Depending on the road surface, BMW's new Integral ABS operates at frequencies between 0.6 Hz (homogeneous, dry asphalt) and 5 Hz (uneven surface such as cobblestones), **Figure 6** and **Figure 7**. The latter high frequency, which reduces the level of riding comfort, is normally not required and is therefore only applied by the system when absolutely necessary.

BMW's Integral ABS features a brake servo for each wheel, with two servo pumps providing the volume uptake required for the two brakes. This allows a greater margin in

operating the brakes, that is, in the process of fine-dosing the brake system. Interacting with the EVO front-wheel brake, the new system reduces the forces required for operating the handbrake lever by up to 50%, **Figure 8**.

The brake servo not only reduces operating forces on the handbrake and/or footbrake lever but also builds up maximum braking pressure more quickly than a conventional brake system. This again helps to shorten the stopping distance, since a reduction in the time required for building up brake pressure by 0.1 s shortens the stopping distance from a speed of 100 km/h by almost 3 m. When applying the brakes, we experience the following fundamental functions in the pressure modulator, **Figure 9**:

3.1 Reinforcement of Braking Power

When the main brake cylinder on the handbrake or footbrake lever is actuated, the control piston is pushed back by hydraulic pressure transmitted via the control arm to a ball in the wheel cycle, Figure 10. At the same time, the hydraulic pump of the brake servo, which is driven by an electric motor, starts up. The pressure that builds up as a result in the wheel cycle presses back onto the control arm via the ball seat, thus creating an equilibrium of forces. The ratio between the control piston and the ball seat area determines the degree of reinforcement in boosting the brakes.

Since the hydraulic pump also provides the brake volume required in the brake system, not only the force for operating the brake lever but also the operating travel is reduced compared to a conventional brake system. The pump is also in a position to compensate for the uptake of overheated brake fluid (with the formation of bubbles) whenever Integral ABS is operated actively.

3.2 ABS Function

Integration of the ABS function into the control valves is far more simple and straightforward than with second-generation ABS II. Instead of the conventional components – the plunger, friction clutch, return spring, and electric motor – only an electromagnetic coil is now required for modulating the braking pressure. This electromagnet acts on the control piston, pulling it back out of the main brake cylinder against the control pressure built up by the rider and thus reducing brake pressure accordingly.

This reveals the main advantage of the new system in comparison with second-generation ABS II. Since the components are much lighter, the lower level of activation energy enables BMW Integral ABS to respond even faster to an unstable wheel by first reducing the braking pressure and subsequently by building up more braking pressure once again.

3.3 Integral Function

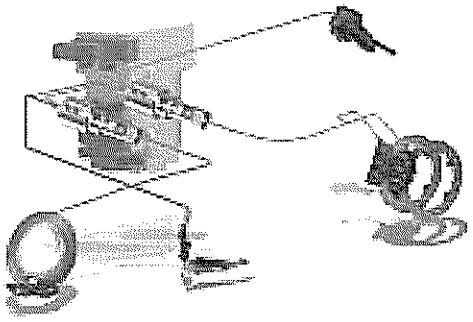
The brake circuits for the front and rear wheel are subdivided in each case into a control and a wheel circuit, thus providing a total of four separate fluid circuits. The control circuit from the operating unit to the pressure modulator is not subject to any thermal load caused, for example, by hot brake discs. The wheel circuit, in turn, accommodates the wear volume required for the brake linings.

Pressure in the control circuit generated when operating the brakes is transferred directly to the control valve on the appropriate wheel (hand lever for the front wheel, footbrake lever for the rear wheel).

The control circuit accommodates a bypass that is able to exert pressure on the control rod of the "other" wheel circuit via an integral piston. With the integral function, the hydraulic pumps are activated via the brake light switch or – if the brake light switch is defective – via the internal pressure sensor, allowing braking pressure to build up on the front and rear wheel at a predefined geometric ratio. Current fed to the coil on the rear wheel circuit and controlled by the pressure measured in the front wheel circuit serves to adjust the braking pressure according to the ideal brake force distribution for each motorcycle.

3.4 Adaptive Brake Force Distribution

Vehicle-specific, dynamic and adaptive brake force distribution is an entirely new feature on the motorcycle. The big advantage of this system is that it feeds exactly the right level of braking pressure to the two wheels in accordance with the brake forces the wheels are actually able to convey to the road. The ideal distribution of brake forces on each kind of road surface and its frictional coefficient depend on the wheelbase and centre of gravity (load!) of a vehicle [3]. With increasing stopping power, this distribution follows a parabolic curve and is masterminded individually for each vehicle by the electronic control system, **Figure 11**.



Principal functions of the fully integral version

BMW Integral ABS is controlled electronically by means of pressure sensors acting on the electromagnetic coil in the rear wheel control valve. As with conventional ABS, brake pressure is reduced via the coil in accordance with the ideal distribution of brake forces.

With brake force distribution being consistently maintained at an almost ideal level, the motorcycle remains more stable when the rider applies the brakes, since both tyres benefit from maximum lateral stability. A further advantage is the smoother and more consistent wear of the brake linings and tyres, and when the brakes are applied on a bend the consistent use of the frictional coefficient available on both wheels improves riding stability.

Brake force distribution is able to "learn" in an adaptive process by detecting the different ratios of brake lock pressure on the front and rear wheel when running under different loads. A motorcycle carrying a passenger and luggage, for example, is able to convey more braking power to the rear wheel than a solo machine. Load conditions and, as a result, the braking power the motorcycle is able to convey to the road (with a suitably adapted ideal brake force distribution curve) are recorded by the electronic control system when the brakes are applied in an ABS process and are consistently adjusted. As a result, the rider is always able to apply the brakes perfectly on his motorcycle regardless of load conditions, thanks to BMW Integral ABS.

4 Residual Brake Function

The control valves are designed to give the rider a residual brake function even when the ignition is switched off and the system is not activated or when BMW Integral ABS

fails to operate, thus again providing the same safety function as in a car.

Although, when using the residual brake function, the rider has to move the brake lever further and apply higher forces than would normally be the case with conventional brakes, he is still able to safely slow the motorcycle down even without the brake servo working. This means that he is able to apply the brakes without problems when manoeuvring the motorcycle with the ignition switched off (and, accordingly, with the brake boosting function deactivated).

5 Integrated Safety Functions

Integral ABS fulfils the high standard of safety required by BMW, for example by warning the rider of all possible malfunctions, **Figure 12**. The system first performs a self-diagnosis when the rider switches on the ignition, with the general warning lamp (with its triangular symbol) coming on for about three seconds and then going off again if the system is working properly. The ABS indicator flashes on and off quickly for about two seconds during self-diagnosis and then starts to flash more slowly until the wheel sensors have been checked for their function at approximately 4 km/h. This indicator then goes off and the system is fully available.

For safety reasons, there is no self-diagnosis function whenever the rider operates a brake lever while switching on the ignition. Once he lets go of the brake lever, however, the self-diagnosis function can be completed and BMW Integral ABS is fully available about two seconds later.

Integral ABS constantly monitors itself while the motorcycle is being ridden, informing the rider immediately of any malfunction. Should the ABS indicator flash on and off quickly while the general warning light is permanently on (or without the general warning light if the self-diagnostic process has not yet been completed), the rider will know that he has only the residual brake function on at least one wheel. With the ABS indicator flashing slowly while the general warning light remains switched on permanently, the rider knows that at least one wheel has no ABS function.

The ABS control unit monitors both the tail light and the brake light. Should the tail light be defective, for example, the general warning light will come on and the brake light will be dimmed to act as a replacement for the tail light (meaning that the brake light will come on again in full as soon as the rider applies the brakes). Should the brake light be defective, the system also activates the general warning light, the only difference in this case being that the tail light cannot take over the function of the brake light. The level of brake fluid in the brake circuits is monitored electronically by floats in the reservoirs, with the ABS indicator and the general warning lamp flashing on and off alternately as soon as the fluid level drops below the minimum point.

Table: A comparison of ABS II and Integral ABS

	ABS II	BMW Integral ABS
Weight of modulator	5.223 kg	4.1 - 4.3 kg (horizontal/upright)
Weight of 2 sensor rings	720 g	260 g
Build-up of brake lock pressure (dry asphalt) - 0 bar/pressure build-up	90 – 105 ms	Generally 80 ms (faster control not sensible in physical terms), up to 30 ms possible in specific cases
Control frequency	0.6 – 5 Hz, depending on road surface	0.6 – 5 Hz, depending on road surface
Integral brake	No	Yes, two variants
Load-dynamic control valve	No	Yes, vehicle-specific
Detection of load conditions	No	With ABS control 1% / 8 ms after the first ABS cycle In practice 1-3 sec until 100% load is fully adapted
ABS control comfort	No pulsation on the brake lever	No pulsation on the brake lever
Reduction in manual forces with the EVO brake		15% each time
Reduction in manual forces EVO + Integral ABS		50% at 6 m/sec_ for R1100 S with Integral ABS versus R1100 S with ABS II
Supervision of tail light	No	Defect warning when appropriate + dimming of brake light
Supervision of brake light	No	Defect warning
Electronic monitoring of brake fluid level	No	Defect warning when below minimum
Wheel sensor operating range	Gap 0.5 +/- 0.05 mm	Gap 0 – 1.7 mm

6 Summary

BMW's new Integral ABS is lighter and offers an even faster and more consistent control function than ABS II, **Table**. When the rider has to apply the brakes suddenly on a straight road, Integral ABS shortens the stopping distance and at the same time prevents the rider from falling due to a locked wheel. The next point is that BMW Integral ABS responds faster than the rider can, especially when applying the brakes all-out on abruptly changing road surfaces. Accordingly, BMW Integral ABS is an important milestone in further improving active riding safety on a motorcycle.

References

[1] Horst Ecker, Achim Fischer: Bremsbeherrschung von Motorradfahrern – Ergebnisse aus einem Großversuch (Ability of Motorcycle Riders to Properly Apply the Brakes - Results of a Large-Scale Study) In: Sicherheit, Umwelt, Zukunft III, Institut für Zweiradsicherheit, 2000.

[2] Kann der Einsatz von Elektronik im Motorrad Unfälle vermeiden? (Can the Use of Electronics in the Motorcycle Prevent Accidents?) In: VDI Reports No 875, 1991

[3] A Weidele, B Breuer: Untersuchungen zum Bremsverhalten von Krafträdern mit und ohne ABS. (Examination of the Brake Behaviour of Motorcycles with and without ABS.) In: VDI Reports No 657, 1987