MOTORCYCLE BRAKING AND ITS INFLUENCE ON SEVERITY OF INJURY

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ABSTRACT

At first glance there seems to be no correlation between braking and injuries, but an in-depth study of fatal motorcycle collisions reveals the cause of accident to be incorrect braking.
Modern motorcycles have excellent brakes but the driver is often overtaxed in pre-accident situations. There is a great risk that even an experienced driver will overbrake the front wheel due to the stress situation.
As an investigation of 613 motorcycle collisions with cars shows, the only solution to this problem is to equip motorcycles with antilock braking systems. The reconstruction and practical analysis of these cases and a collaboration with the University of Darmstadt showed the different braking parameters, reduced braking distance and increased stability. The study also demonstrates the influence of different motorcycle and driver movement during the impact with or without a fall after emergency braking. This has a direct effect on the type of injuries suffered. Secondary safety elements of the motorcycle are greatly reduced if the motorcycle driver falls prior to the collision.
Finally a list of proposals is presented for optimizing motorcycle braking systems.
A theoretical presupposition for positive influence by a ALB system is given in more than 50% of all motorcycle accidents.

In more than 90% of all accidents involving a fall prior to the collision, an ALB system could have been completely prevented the fall. This would result in a substantial reduction of serious and fatal injuries to motorcycle drivers

INTRODUCTION

Risk of Injury

The risk of a motorcycle driver injuring himself is determined largely by the movement characteristics during the collision or fall. Since the driver of a two-wheeled vehicle does not wear a belt that connects him to his vehicle nor is there a passenger compartment that could impede his free movement, there are a wide variety of ways in which driver and vehicle can disengage.

In all cases in which the motorcycle driver can avoid direct contact with the other party's vehicle, the severity of his injuries is clearly lower than if there is impact with the other vehicle.
Passive safety elements such as padding /1/, which prevent the driver from getting caught on the handlebars, and special-purpose motorcycle airbags /2/ can help to initiate a desirable trajectory. Unfortunately, these components have not yet appeared on the market.
Nevertheless, the accident figures in Germany declined from 1991 to 1998 /3/.

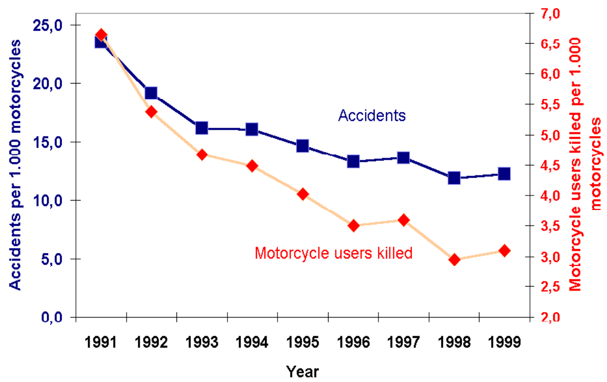

Figure 1: Accidents involving motorcycles and driver fatalities /3/

What is alarming, however, is that since 1999 the accident figures have been rising, both with respect to the number of accidents that have occurred and with respect to the number of motorcycle drivers fatally injured.

As far as passive safety is concerned, the motorcycle has always been at a disadvantage compared to the car. This becomes clear from a comparison of accident figures of both vehicles over a period of time in which a clear attempt was being made to constantly improve car safety.

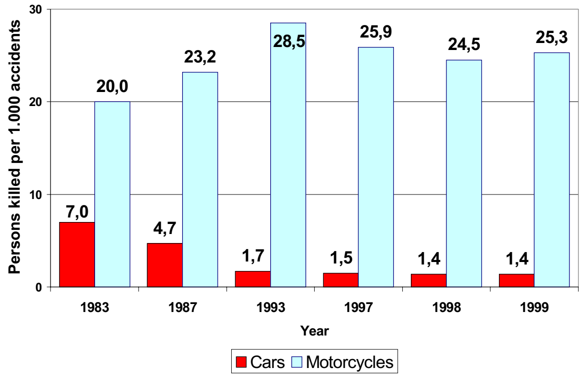

Figure 2: Risk of being killed in an accident

Whereas the risk of being killed in a car accident clearly drops from 7 fatalities per 1000 accidents to 1.4 fatalities, the number of motorcycle drivers killed remains constant. This is a clear indication of the lack of improvement in passive safety.

Relatively constant passive safety with an increasing number of accident victims based on the total number of accidents indicates a change in the sequence of events that occur during an accident.

The hypothesis of a changed trajectory of movement might be one explanation, since the dominating factor for the severity of injury in accidents involving two-wheel vehicles is not the speed of collision /4/ but rather the way in which energy is dissipated during the collision phase, i.e. the distance the driver is thrown, contact sites and other movement-specific parameters.

ACCIDENT ANALYSIS

Sample Accidents

An analysis of three fatal motorcycle accidents which occurred during a period of two months provided another indication of a change in the risk of injury. All three accidents occurred near Munich within a radius of 50 km and had the following factors in common.

The motorcycles were new, none more than a year old; road conditions were ideal: dry road surface and sunshine. Collision speed was less than 100 km/h. The injuries suffered by the motorcycle drivers were caused by the impact of the driver's body on the lower parts of the car. The most distinct indication of a changed trajectory lies in the fact that all motorcycle drivers fell prior to the collision.

This fall therefore became the focus of all subsequent studies. The reconstruction of these cases resulted in the following sequence of events leading up to the accident:

In the first case, a motorcycle driver collided with a car approaching from the left. The car turned into the direction in which the motorcycle was travelling. The moment the motorcycle driver realized the car was going to intersect his path, he slammed on the brakes which immediately caused him to fall. The remaining inertia caused the driver's body to slide against the rear car fender and he most probably was trapped between his motorcycle and the car. Despite only minor visible external injuries, the motorcycle driver died of internal injuries.

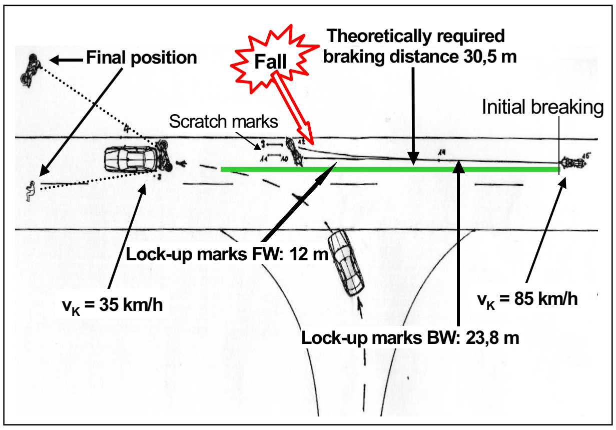

Figure 3: Accident sample

If we vary the initial situation such that the driver is assumed to have applied the brakes in a controlled manner at the same reaction point and without a fall, the result is an entirely different course of events in this accident situation. In this case, the motorcycle driver would have been able to stop his motorcycle and the collision could have been avoided entirely.

In the second example that follows, it might not have been possible to avoid the accident either, but it is highly likely that the consequences would not have been fatal. In this case as well, the motorcycle driver fell and suffered fatal injuries when his body slammed against the front axle of the car. Figure 4, which depicts the crash position, demonstrates that this driver was also jammed between the car and his own motorcycle.

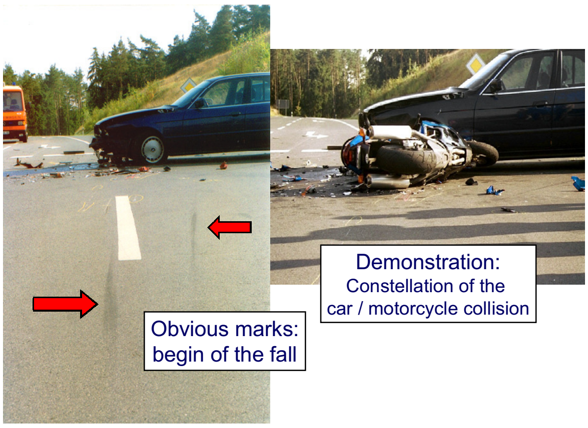

Figure 4: Case 2 - crash position

The third case occurred at the beginning of a curve. Startled by an oncoming vehicle, the motorcycle driver applied the brakes in panic, fell and slid tangentially into the oncoming traffic, where he sustained fatal injuries as he slammed against the lower front portion of a car.

In summary in all three cases, the fall was responsible for the severe injuries that were sustained, in these cases they were fatal.

DATABASE ANALYSIS

The motorcycle database of the Institute for Vehicle Safety includes 610 motorcycle/car collisions as well as 300 single-vehicle accidents involving motorcycles, in which at least one motorcycle driver was injured. The data was obtained from the accident files of German car insurers and covers the period from 1990 to 1997. This data was used for an in-depth analysis of the sequence of events that occur during an accident.

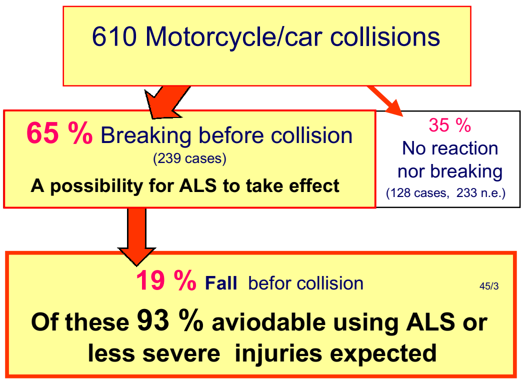

Figure 5: Accident database, car/motorcycle collisions

In about one-third of the 610 car/motorcycle collisions, the accident occurred without a reaction from the motorcycle driver /4/. In 239 accidents (65%), the motorcycle driver was able to apply the brakes prior to the actual collision. In this group of motorcycle drivers who were able to brake before the collision, 19% fell.

These 45 accidents were then subjected to an in-depth analysis of each individual case designed to clarify whether or not an ALB would have been able to have prevented the driver's fall.

In almost all of these accidents (93%), we were able to answer this question in the affirmative, i.e. if the brakes had been applied in a controlled manner, the motorcycle driver would not have fallen. In approx. 15% of these cases, the accident could have been prevented entirely and in the remaining cases, the impact velocity would in any case have been reduced. At the same time, the sequence of movements would have taken a turn for to better for the motorcycle driver, since he would have collided with the other vehicle in an upright position. This would have favored a disengagement of the driver from the motorcycle and probably would have caused the driver to fly over the car.

As the studies /5/ demonstrated, the risk of injury in the event of a fly-over is markedly reduced compared with an impact against the same vehicle.
The following picture, in which a distinction is made between accidents with and without a fall, shows this reduction in the severity of injury when a fall is avoided.

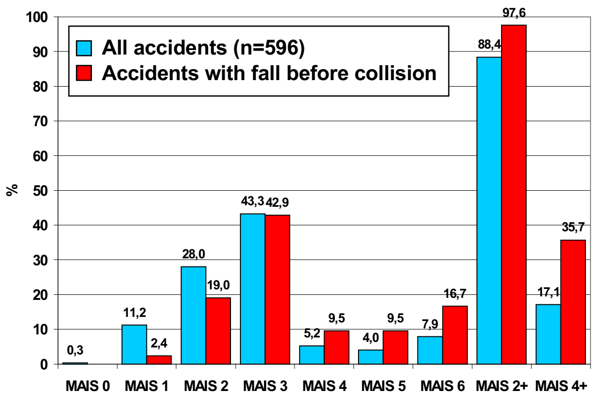

Figure 6: Injury severity with and without a fall

The danger of suffering a critical MAIS 4+ injury doubles in the case of a motorcycle driver

who falls prior to collision. In addition, fatal injuries are more than double as frequent in this group.
In the 300 single-vehicle accidents the Institute studied /6/, a fall was observed in 40% of all accidents before the motorcycle driver had left the road or collided with an obstacle.

The conclusion is that a fall drastically multiplies the risk of injury. Measures must be taken to prevent such falls in the event of panic braking. An anti-locking system (ALB) can fulfill this function.

Braking Technique

The correlation between fall, incorrect braking and the dramatic consequences of accidents makes it clear that, although motorcycle braking achieves high deceleration values, it does not comply with the state of the art /7/.

It can be considered to be an anachronism that, at a time at which it is virtually impossible for a car driver to make a mistake due to ABS, brake assist and ESP systems, the motorcycle driver must still use one hand and one feet to actuate two completely independent braking systems while at the same time still ensuring the stability of his single-track motor vehicle.

Although most drivers accomplish this in almost all cases without too many problems, the motorcycle driver is hopelessly unable to cope in the case of panic braking. Either he is so startled that he overactivates the front-wheel brake, thus locking the front wheel, or he fails to apply the front-wheel brake enough for fear of locking the front wheel. In either case, he extends his stopping distance or, even worse, he will inevitably fall in the first case.

And to make things even more complicated, the laws of physics also stack up against the motorcycle driver. Weidele /8/ first described the dynamic overbraking of the front wheel as early as 1994. This comes about due to the different gradients in the growing braking force and dynamic axle load displacement in very rapid braking operations such as in panic braking.
In an experimental study commissioned by the Institute for Vehicle Safety, the Technical University of Darmstadt /9/ proved these theoretical observations in practice.

For this purpose, a normal touring motorcycle was provided with measuring devices to measure the braking force exerted on the front wheel, the distance the front-wheel fork spring is compressed and the circumferential speed of the front wheel.

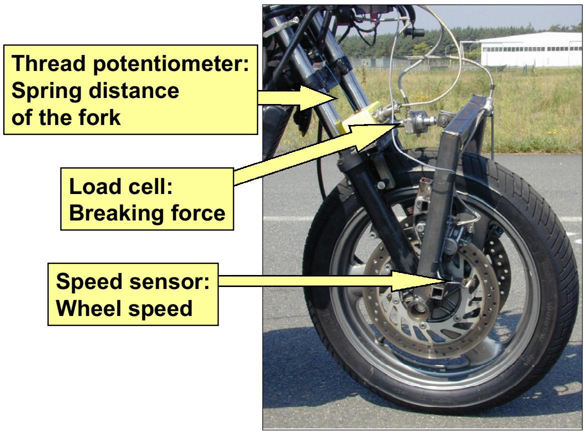

Figure 7: Experimental setup: Measurement of the wheel forces

The load on the front wheel was measured via the distance of spring compression and the speed of spring compression with the motorcycle mounted stationary in a shock absorber test bench. The results may also be applied to the road trial if it is assumed that the road surface was level and that the motorcycle frame had a high spring stiffness.
The diagrams shown below contain the measurements obtained from the trials conducted. The course of the trial will be discussed on the basis of the following diagram and represents the approach used for the entire trial run.

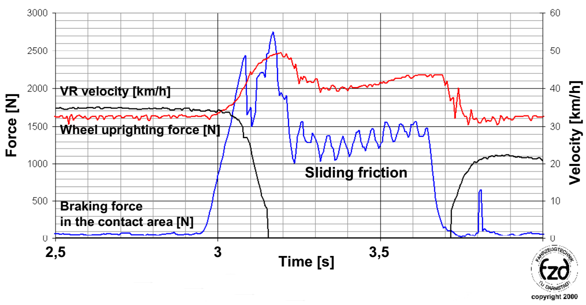

Figure 8: Measurement data

The test driver drives over the test track at a velocity of approx. 35 km/h and initiates a braking force at t = 2.95 sec. After a very short brake response time, a period begins in which the brake pressure and thus the brake force rise. In this particular case, this occurs at a gradient of approx. 15,700 N/s, whereas the wheel load only

increases approx. 2,900 N/s after a delay time of approx. 0.04 s. As soon as tire-road adhesion has been exceeded (coefficient of friction approx. 1.1), the front wheel begins to lock up.
At t = 3,15 s, the wheel lock-up causes a reduction in tire-road adhesion due to the sliding friction now prevailing, thus to a decrease in brake delay and to a reduction in front wheel load. The tire slides over the road surface and in the present example – in combination with small surface irregularities, among other things – causes brake force fluctuations with a frequency of approx. 25 Hz. While all this is happening, the wheel load and brake force mutually influence one another and gradually approach the value for a locked-up front wheel. The opening of the brake, which becomes necessary due to the instability of the motorcycle, occurs at the beginning of brake release with a brake force gradient of approx. –27,800 N/s.
The front wheel does not begin to rotate again until 0.06 s after brake release and does not roll freely until a full 0.2 s after brake release when it is once again able to transmit a lateral component, thus positively contributing to gyrostabilization. In this case, the relatively long duration corresponds to a distance of more than a meter and is all the more alarming since the trial was carried out at a relatively low velocity. At high velocities the angular acceleration of the front wheel will bring about a significantly longer duration and disproportionately longer distances.
These physical conditions will be more severe in real accident situations because of the higher speeds and the unprepared driver.

To sum up, in the event of panic braking, even experienced motorcycle driver hardly have a chance of not overbraking the front wheel, since the laws of physics favor wheel lock-up.

The Interaction of Active and Passive Safety

An anti-lock brake system can do more for the safety of the motorcycle driver. As far as active safety is concerned, i.e. accident avoidance, prevention of a fall and optimum utilization of braking power would have achieved the shortest stopping distance, thus preventing the accident in approx. 15% of the cases studied.
In the remaining cases, the active ALB safety element has demonstrated its effect in the field of passive safety.
There are relatively few passive safety elements for motorcycles /10/. The state of the art consists of optimum protective clothing together with a good helmet as well as a motorcycle design which prevents the driver from getting caught in parts of the motorcycle. Padding which affects the path of movement or reduces the effects of external forces is still in the testing phase. Although the motorcycle airbag has been under consideration for 15 years, it has not been propagated except for a few prototypes.
All these measures can only be effective if the motorcycle driver involved in an accident collides with the other party while sitting in an upright position. Even if one day there is a special-purpose airbag for motorcycles, this would only be effective if the driver has not fallen prior to the collision. Moreover, all attempts to guide the motorcycle driver over the other party, thus reducing the severity of injury, can only be effective if a fall can be avoided.

The bottom line: All attempts to develop passive safety elements are actually doomed to failure unless an improved brake system featuring ALB is provided to exclude the high risk of falling prior to the collision.

CONCLUSION

It must not be the sole objective of accident research to compile the principal factors of accidents and point out safety shortcomings. It must also utilize all possibilities to put research results into practice and to ensure continuity in safety improvement measures.
As far as Germany is concerned, the introduction of ALB for all sport and touring motorbikes would bring about a 10% reduction in the number of all accidents. This would mean in absolute terms that 90 motorcycle drivers would not be killed on German roads and about 3000 accidents, which the motorcycle driver was seriously injured owing to a fall, could be avoided.

There are three different approaches that can be taken to ensure that endangered motorcycles should be equipped with ALB.

1. First of all, the motorcycle driver himself is the most important person to talk to. As long as there is still prejudice with respect to ALB systems and they are considered unnecessary, industry will not be interested in placing more offers on the market.
   At the moment, there is only one motorcycle

manufacturer who equips almost his entire vehicle fleet with ALB. Many manufacturers have taken their ALB motorcycles off the market again.

2. In order to call the motorcycle driver's attention to this problem as early as possible, driver education schools are called upon to discuss this topic sufficiently. The fact that many improvements are still possible in this field is demonstrated by a peculiar feature of the German exam regulations for motorcycle driver's licenses.

   If a learner driver does not dare to make the required full braking at a speed of 50 km/h using a conventional brake system, he is allowed to use an ALB motorcycle for this part of the examination. We consider this to be extremely dangerous. At the very least, the motorcycle driver should have an entry made in his driver's license in such cases to the effect that he is only allowed to drive vehicles equipped with ALB. The same regulation has applied for years to cars equipped with automatic transmissions.

3. If we succeed in changing the attitude of motorcycle drivers and get continuing education and further training to focus on the topic of ALB, then industry will be induced to offer ALB motorcycles and reduce the costs, thus making it more attractive to everyone. This would be yet another step towards enhanced safety on motorcycles.

Literatur

/1/ A. Sporner, K. Langwieder, J. Polauke:“ Passive Safety for Motorcyclists – From the Legprotector to the Airbag“, GDV, Institut für Fahrzeugsicherheit, SAE Congress Detroit, Michigan, 1990

/2/ A. Sporner, K. Langwieder, J. Polauke: Passive Sicherheit am Motorrad. Kritische Beurteilung der Einsatzmöglichkeiten von Airbags, HUK-Verband, Institut für Zweiradsicherheit e.V., Deutschland, Bochum, 1987

/3/ Statistisches Bundesamt Wiesbaden, Fachserie 8: Verkehr, Reihe 7: “Verkehrsunfälle“, Verlag Metzler-Poeschel, Stuttgart

/4/ A. Sporner, T. Kramlich: „Zusammenspiel von aktiver und passiver Sicherheit bei Motorradunfällen“, GDV, Institut für Fahrzeugsicherheit München, 3. Internationale Motorradkonferenz, München, 2000

/5/ A. Sporner, K. Langwieder, J. Polauke: „Delelopment of a Safety Concept for Motorcycles – Results of Accident Analysis and of Crash Tests“, HUK-Verband, Institut für Zweiradsicherheit, ESV – Conference, Washington D.C., May 1987

/6/ Lechner, Matthias: Der Zweirad-Alleinunfall, Allianz Zentrum für Technik, Deutschland, München, 1986

/7/ B. Breuer, A. Weidele, W. Schott: „Kraftradbremsen – ABV und Kurvenbremsung“, Internationales Symposium Forschung & neue Technologie in Verkehr, Köln 1989

/8/ A. Weidele: „Untersuchungen zum Bremsverhalten von Motorrädern unter besonderer Berücksichtigung der ABS-geregelten Kurvenbremsung“, Technische Hochschule Darmstadt, VDI-Verlag, Darmstadt, 1994

/9/ J. Funke, B. Breuer: „Dynamische Vorderradüberbremsung bei Motorrädern“, Forschungsbericht, Technische Universität Darmstadt, September 2000

/10/ M. Danner, K. Langwieder, A. Sporner: „Accidents of Motorcyclists – Increase of Safety by Technical Measures on the Basis of Knowledge Derived From Real-Life Accidents“, HUK-Verband, Institut für Zweiradsicherheit, ESV – Conference, Oxford, 1985

Further Literatur

Stoffregen: Vorlesungsskript „Motorradtechnik“ - Grundlagen und Konzepte von Motor, Antrieb und Fahrwerk, 3. Auflage, Braunschweig / Wiesbaden, 1999

A. Weidele, M. Schmieder: „Kraftradbremsen – ABV und Kurvenbremsung“, Forschungsbericht der Bundesanstalt für Straßenwesen (BAST), Bergisch Gladbach, 1989

A. Weidele: „Kraftradbremsen – ABS – geregelte Kurvenbremsung unter Berücksichtigung von Kraftschlussausnutzung, Fahrstabilität und Kurshaltung“, Forschungsbericht der Bundesanstalt für Straßenwesen (BAST), Bergisch Gladbach, 1992

H.-P. Willumeit: „Nick- und Hubbewegung, Radlasten und Umfangskräfte beim Abbremsen eines Motorrades“ VDI Berichte, Motorrad – 6. Fachtagung, Köln, Oktober 1994

B. Spiegel: „Über das Bremsen aus der Sicht des Verhaltensforschers“, Fortschritt Berichte VDI, XX. Internationales µ-Symposium, Bremsen-Fachtagung, Bad Neuenahr, Deutschland, 2000

J. Präckel: „Das Bremsverhalten von Motorradfahrern – ein Beitrag zur Mensch/Maschine Schnittstelle“, VDI Berichte, Motorrad – 6. Fachtagung, Köln, Oktober 1994

J. Präckel: „Bremsverhalten von Fahrern von Motorrädern mit und ohne ABS“, Forschungsbericht der Bundesanstalt für Straßenwesen (BAST), Heft F 18, Bergisch Gladbach, 1996

J. Präckel, V. Bachmann, B. Breuer: „An University‘s View on Motorcycle Safety – Recent Research Results and Further Perspectives“, National Highway Traffic Safety Administration (NHTSA), 15th ESV-Conference, Melbourne, Australien, 1996