# SAFETY POTENTIAL OF FUTURE TWO-WHEEL CONCEPTS - A CHALLENGE

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## ABSTRACT

Many big cities in Europe and elsewhere in the world have problems managing the traffic especially during rush hours. The improvement of the parking problematic and environmental protection as well are important aspects for the future traffic design of urban areas. To improve the traffic situation the development of new traffic concepts and alternative vehicles are required.

The BMW company has developed a new type of two-wheel vehicle. This two-wheeler constitutes a totally new concept. BMW implemented a lot of safety features, such as a structure made up of rollover bars and a crush element instead of a front protecting plate. Furthermore the driver can secure himself with two safety belts.

The paper contains a description of the novel two-wheel vehicle concept designed so far. BMW's concept and the safety features are also explained. The Federal Highway Research Institute (BASt) was given the task of assessing the concept as a whole with regard to the active and passive safety and the exemption of the obligation to wear a helmet. The expertise concluded, that the BMW two-wheeler concept has a very high safety standard. Some extracts of the expertise, in particular the investigations concerning the exemption of the obligation to wear a helmet are presented. Common legal requirements for the vehicle registration of vehicle concepts similar to the BMW two-wheeler in Germany have been formulated.

### INTRODUCTION

Private transportation in 1994 made up 81% of total passenger transportation in Germany, with 44.56 million people being transported.

It is being attempted to shift private transportation out of the overcrowded centres and cities into the outskirts through transportation-related political measures. Many cities are hardly able to manage transportation at peak times because of the great increase in traffic, the borders in designing the flow of traffic as well as the limitations in building traffic ways. If you look at the average number of people in an automobile in city traffic (approx. 1.5 people per vehicle) you can see that a very unfavourable relationship between the number of transported people per automobile exists related to the required traffic space. Improvement through an increased utilisation of vehicles, for example through carpooling or alternative vehicle concepts in which vehicles require less traffic space would be possible solutions.

The last thought mentioned has been investigated for a long time now in regards to transposing special city vehicles to private means of transportation. An appropriate two-wheel vehicle for a new class of vehicles has been intensively discussed since the beginning of the 90s (SAMMER et al.), (HEINZE, 1991), (SIEVERT, 1997). This new type of two-wheel vehicle could represent a contribution to the solution of traffic problems in overcrowded areas. Aspects such as environmental protection as well as saving traffic and parking space play a big role in this. According to a study by SAMMER et al., there can be a 7% shifting expected in the portion of the road it takes up in such "new motorised two-wheel vehicle" in appropriate infrastructure conditions.

There is currently no precise definition of this possible new class of two-wheelers. Two and three-wheelers similar to motor-scooters with (partially) enclosed body structures or cabins are imaginable which can be used more as a means of transport fit for city and day-to-day traffic rather than as leisure time equipment. The literature locations named above as well as articles on the (functional) motorcycle of the future (ROUX et al, 1991), (WEIDELE, 1991) contain some possible characteristics as well as requirements of this new type of vehicle class:

- high user friendliness (for example automatic gears, easy handling, low-maintenance operation)
- comfort and weather protection
- high requirements for passive safety (if need be without a helmet or protective clothing)
- roof structure, closed cabin, leg protection
- stabilising aids in a standing position
- variable transport capacity.

The Honda model „Canopy", in which the construction is connected to the two-wheeler's back axle via a pivoting joint, as well as the „Bunny" model by TGB (SAMMER et al.), (MOTORRADKATALOG, 1996) can be named as examples of vehicles that point in this direction.

This concept has now been picked up by a large German two-wheeler manufacturer (Bayerische Motorenwerke - BMW AG) along with the C1 concept. This vehicle's idea was developed in 1991. In 1992 the C1 concept was presented within the framework of a talk at the VDI Motorcycle Conference with the title "Means of Transportation from the Future, Structural Interpretation of a Two-Wheel Safety Frame" (NURTSCH, 1993). That same year, BMW AG showed a conceptual study on C1 at the IFMA in order to investigate customer response. There it was shown that acceptance is heavily dependent on criteria such as maintaining individuality during transportation, extensive comfort as in an automobile (minimal weather-dependence, for example) and a high level of safety. Freedom from helmet laws has proven to be decisive for the vehicle's market acceptance.

The Federal Highway Research Institute (BASt) investigated the question of exemption of the obligation to wear a helmet for this two-wheeler and took on a thorough evaluation of active and passive safety. The documentation from 11 crash tests (see table 1) and additional computer simulations were available for this. Furthermore, various documents were evaluated, investigations and test drivings were carried out and meetings were held. Knowledge from discussions in the expert committee on Motor Vehicle Technology (FKT), special committee on "two-wheel vehicles" was brought in.

In addition, the BASt carried out a literature study and analysed crash tests run on the occasion of other projects.

The BASt conducted an inquiry at the Medical University of Hanover (Medizinische Hochschule Hannover - MHH) in order to get an evaluation of head injury risks from today's two-wheeler from the perspective of accident analysis. The carry-over of these results to the C1 two-wheeler remain unclear since this vehicle follows another concept (a buckled-up passenger, for example) which leads to different accident kinematics (no separation of driver and vehicle during the accident). Since these new types of two-wheel vehicles are not represented in today's traffic occurrences there are no accident data available. A possible similar group for comparison is formed by motor-scooters.

## REAL WORLD ACCIDENT OF MOTORIZED TWO-WHEELER

In an evaluation of MHH within the BASt project "On the Spot Accident Surveys" relevant data from 1985 to 1995 about motorcycle (>80 ccm / n=776) and motor-scooter (<80 ccm and >80 ccm / n=89) accidents were compared (OTTE, 1996). The distribution regarding the frequency of the occurrences of certain collisions is shown in table 1.

A motor-scooter accident frequency rate of 88.9% in the city is higher than that of motorcycles (79.2%). The objects with which motor-scooters collided are less commonly automobiles and trucks in comparison to motorcycles, rather more often bicycles, pedestrians as well as objects.
The relative speed between the two-wheeler and the opposing vehicle is especially relevant for injury severity. Motor-scooters are less powerfully motorised than the motorcycles in the investigated collective. Accordingly, relative speeds in accidents with these vehicles are distinctly lower than in those with motorcycles. It can be seen that the proportion of head injuries and their severity increase along with increasing relative speed between the two-wheeler and the object with which it collided.

**Table 1.**
**Collision types (OTTE, 1996)**

| | Type 1 Side-impact by car | Type 2 Frontal impact between car and two-wheeler | Type 3 90° side-impact by two-wheeler | Type 4 oblique impact from the side by two-wheeler | Type 5 Rear collision by two-wheeler | Type 6 Rear collision by car | Type 7 Solo accidents of the two-wheeler |
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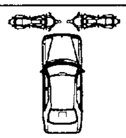
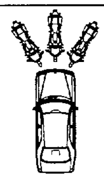
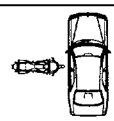
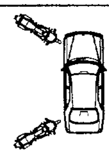
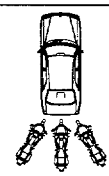
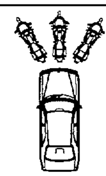
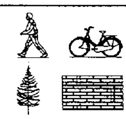
| |  |  |  |  |  |  |  |
| frequency at motor-scooter | 5,1% | 22,3% | 7,0% | 16,7% | 5,2% | - | 43,7% |
| frequency at motorcycle | 4,2% | 18,3% | 5,9% | 25,7% | 11,2% | - | 34,7% |

If one compares the severity of head injuries in the different collision types for motorcycles and motor-scooters, the result is the ranking shown in table 2 for the most important collision types for each.

**Table 2.**
**Representation of the three most important collision types regarding head injuries for accidents with motorcycles and motor-scooter** (OTTE, 1996)

| | Collision type | Frequency of head injuries with AIS 2+ |
|---|---|---|
| Motorcycle: | Type 3 | 11,5% |
| | Type 7 | 9,2% |
| | Type 4 | 9,1% |
| Motor-scooter: | Type 4 | 6,8% |
| | Type 7 | 5,0% |
| | Type 2 | 2,0% |

In all, head impacts are not of great consequence because of high helmet-wearing rates (approx. 90% of the accidents with AIS<2).

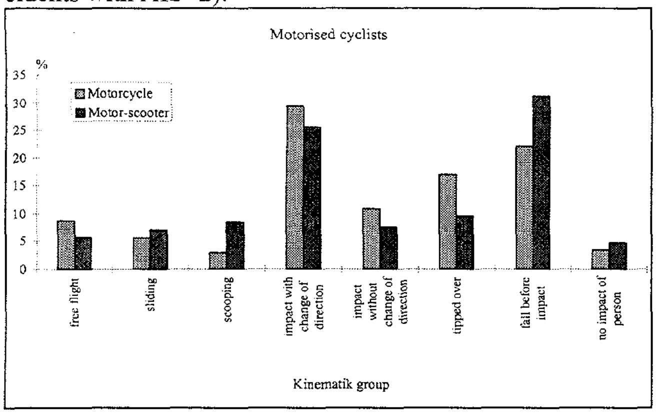



**Figure 1: Cinematic groups and frequency distribution for motorcycles and motor-scooters (OTTE, 1996)**

If one investigates head injuries concerning impact site it is shown that approx. 59% of head injuries occur through impact with the street. Impact with the opposing vehicle is the cause for 17% of motorcyclists' head injuries and 19% of motor-scooter drivers'. An analysis of head impact locations concerning the occurring degree of injury severity to the head shows that head impact against the colliding object count among those with the most severe consequences for motorcycle and motor-scooter drivers. The commonly occurring fall to the street leads, however, to predominantly minor injuries.

The cyclist's movement is based on studies up to now and presented according to the kinematic group definition (Figure 1). If one analyses head injuries regarding kinematic groups, the most head injuries occur in impacts with directional changes (approx. 25%-30%), in the two-wheeler's sideways movement on impact: falling over (approx. 10%-17%) as well as in isolated falling from the two-wheel vehicle (approx. 22%-31%).

## THE TWO-WHEEL CONCEPT

BMW's newly developed two-wheel concept with the internal designation C1 is shown in figure 2.

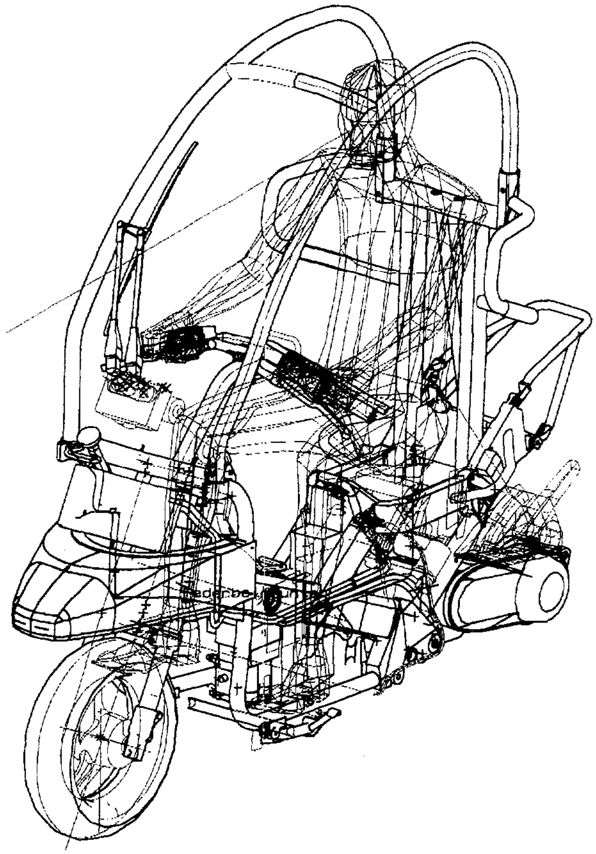


**Figure 2: presentation of the principles of the C1 two-wheeler concept**

The driver sits upright on this two-wheeler and is secured through a belt system. In order to assure survival space for the rider in case of a crash, a special frame structure with an integrated roll bar was developed. This, at the same time, offers extensive protection from weather influences. In addition the vehicle has a crumple zone in the front.

The C1 vehicle is, for the time being, constructed as a light motorcycle with one seat (EC definition). The two-wheeler should reach a maximum speed of approx. 100 km/h. It should be used above all at medium distances (20-50 km) in overcrowded centres. The conventional brake system will be offered with a specially equipped ABS. The handlebar is horizontal and adjustable in the vehicle's lengthwise direction.

The vehicle's special characteristics regarding passive safety are:

- The C1 vehicle is a two-wheeler with a safety frame structure made of aluminium (weight approx. 20 kg). The roll bars are integrated in these frames which also form the protective space for the rider.
- The roof frame structure was put through a roof crush resistance test derived from the test for passenger cells in automobile construction in the USA (FMVSS 216). In this test, the structure must remain with a maximum deformation of 127 mm against a semi-static pressure of at least 22 kN. In the C1 two-wheel a maximum pressure of 26 kN was measured with a given deformation of 127 mm. The roof frame structure should prevent injuries in alone accidents and/or secondary impacts.
- The two-wheeler is equipped with a restraining system that is composed of two separate belt systems, one three-point belt and one two-point shoulder belt. The three-point belt consists of a shoulder belt and a lap belt. The belt systems are installed so that the shoulder belts cross the chest of the rider. The belt anchoring and belt deflection points are fastened to the safety frame structure. According to the test specifications for belt anchors in passenger cars according to ECE-R14, the anchors of three-point belts with retractors (roll-up mechanism) and two point belts must be able to bear a tensile force of 13.5 kN over a period of at least 0.2 seconds. The three-point belt as well as the two-point belt each fulfils this requirement.
- The C1 two-wheeler has a safety seat. In the area at the front of the sitting area the seat was formed so that the riders are prevented from slipping through under the lap belt (submarining).
- There are safety bars attached to the left and right of the pelvic and shoulder areas which should extensively prevent the rider's upper body from leaving the area protected by the bar from the side as well as the intrusion of large vehicle parts and obstacles. These bars will be changed somewhat in the series vehicle in order to achieve a better protective effect. The newest version of the C1 is not equipped with a pelvic bar any more.
- Rather than a protective plate there is a deformable element (crash element) planned with which it is possible to reduce defined energy in a space of 300 mm. The crash element is especially designed for frontal impacts. If the crash element meets an obstacle or a collision opponent, the forces occurring during impact are induced with a relatively minimal vertical distance to the C1's centre of gravity as a result of the element's construction height. That leads to a minor lever-arm to the vehicle's centre of gravity. Through this, the tendency of the C1 two-wheel to lift itself with the rear end far from the road and, as a result, possibly to turn over is reduced.
- The front wheel suspension is realised through a „Telelever“ spring fork with pitch compensation. The „Telelever“ spring fork's special feature is that there is a support built in between the sliding tubes of the fork and the frame of the vehicle. At the attachment points the support is flexibly placed. The support causes stronger forces to be able to be absorbed through the spring fork. The „Telelever“ spring fork together with the crash element therefore determine the behaviour in frontal accidents since they are involved in reducing the collision energy.
- There is a windshield build into the roll bars in the driver's field of view. In the current design, a tempered safety glass was used for technical manufacturing reasons.

## EVALUATION OF THE C1 TWO-WHEELER'S ACTIVE SAFETY

All technical vehicle measures which contribute to accident avoidance are understood under active safety. For two-wheelers it is especially important to look at the driver, vehicle and surrounding components as a complex, whole system rather than isolated since the driver actively and passively contributes to stabilisation through the coupling and because the two-wheeler reacts especially sensitively to interference from its surroundings. The whole system's performance ability regarding the task of accident avoidance is not only dependent on the assumptions of the driver, motorcycle and surroundings rather also on the interplay of these components.

Next to driving safety and driving behaviour, other important aspects of active safety are the operating and information concepts as well as the condition, perceptive, and system safety.

### Special features of active safety and passive safety's objective conflicts in new types of two-wheel concepts

The characteristics and requirements of this new class of two-wheelers named in the introduction point to the fact that there are special aspects to be taken into consideration regarding active safety:

- driving behaviour at lower speeds
- wind influences in connection with the covering and vehicle's construction
- viewing conditions.

Next to constructive conditions, fixing the driver's upper body to the vehicle (seat belt, for example) as well as leg freedom of movement (weather protection, leg protection) play a role in stabilising the vehicle at low speeds. Objective conflicts can occur here in passive safety. Vehicle stabilisation problems at low speeds as well as in a standing position are increased through a constructively conditioned high position of centre of gravity. The appropriate support systems or support wheels may possibly be realised which, depending on the design, could lead to problems in driving behaviour at higher speeds. The foot space width or possible support device could have a negative effect on the ground clearance when banking of the vehicle.

Impairments through wind influences (side winds, whirlwinds) could develop from constructions designed for weather protection such as the covering, roof or closed cabin which influence driving stability.

The vehicle's frame posts and there padding have a negative influence on the field of vision. This especially plays a role if, during simultaneous wearing of a helmet, the field of vision is already restricted. Concerning the vehicle's "windshield", aspects such as windshield wipers and washers, ventilation against steaminess as well as scratching the shield play a role. The last point mentioned especially if plastic shields are used according to the current stand of technology. On the other hand, a plastic shield would be advantageous based on the height of the centre of gravity and passive safety.

The following points can be named as further aspects of active safety which possibly play a special role:

- By realising a high level of comfort and weather protection, positive effects on condition safety are to be expected.
- If starting were planned to be prevented through ignition interruption as an assurance of seatbelt use, dangerous situations could result from malfunctions during use when driving.
- 
- Ability to recognise as well as identify a vehicle as a single-track vehicle is especially important in vehicles that will be used in city areas (SPORNER et al., 1993).

**Assessment of the C1 two-wheeler's active safety**

The judgement of the C1 concept's active safety is based on information from BMW AG as well as on impressions from test-drives.

When judging aspects of active safety it can be said that this, with the exception of the technical type approval regulations to be complied with, is only subjectively possible since the necessary criteria, test processes and limiting values do not exist. There were, in the past, estimates (see SCHMIEDER, 1991; SCHWEERS, 1991), but in general it can be assumed that active safety and especially a two-wheeler's driving behaviour cannot be evaluated through objective processes.

On principle, the presented C1 concept's active safety is positively judged. This can be explained especially in the following way:

- The special features that are carried by this new class of vehicle are well solved with the C1 concept and do not strike one as negative.
- The C1 concept has special equipment to increase active safety and customers are also given the opportunity to upgrade through special equipment such as ABS.
- According to statements from BMW AG and the responsible technical service, all technical vehicle type approval regulations have been complied with according to EC laws.

The vehicle can be well stabilised at lower speeds, is manoeuvrable and has no stability problems while driving at higher speeds. Relative to wind sensitivity and especially also with regard to side wind sensitivity, there is no negative behaviour present in the vehicle. According to statements from BMW AG tests have been made regarding this. There are, however, no measurements. There are no objective criteria known for judging side wind sensitivity. Through this vehicle's striking design and paint it can be assumed that good perceptibility has been achieved which is important for city traffic.

## EVALUATION OF THE C1 TWO-WHEELER'S PASSIVE SAFETY

Since the C1 vehicle from BMW, as previously mentioned, can not be definitively assigned to any existing type of vehicle it is being tried to define certain accident sequences and accident phases (primary collisions, for example) in which driver strain can be evaluated. Based on the vehicle structure (safety frame structure, belt system, crash element above the front wheel, safety seat for example) the C1 vehicle is close to a comparison with a car in frontal impact. Since the balance of the driver-motorcycle system, consisting of C1 vehicle and seat, after the primary impact has a deciding influence on the accident's further progression, the C1 vehicle is to be compared with a motorcycle or a motor-scooter from this point on. For all other accident constellations, especially the side impact, driver strain evaluation and vehicle behaviour for the whole collision process will be drawn from a motor-scooter or motorcycle as a comparative vehicle.

**Test results and their evaluation**

BMW AG tested two ISO accident constellations (see table 3 and table 4), once each for the C1 vehicle and a conventional motor-scooter. In addition, one of the accident constellations was tested according to ISO for the C1 vehicle occupied with driver and pillion (see table 3).

The two-wheeler's oblique side impact (collision type 4 according to MHH, see table 1 as well as accident constellations 4 and 5 according to ISO, see table 4) which occurs very frequently in real world accidents was recently investigated by BMW AG in crash tests. The results have to be investigated. In addition to both accident constellations corresponding to ISO 13232, further tests were carried out according to BMW AG's own points which, however, based on the ISO and MHH constellations. For all planned test constellations according to ISO norm (ISO 13232, 1995) there were computer simulations carried out.

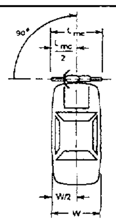
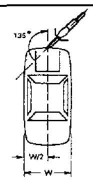
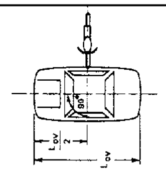
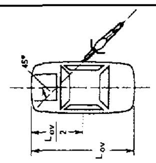
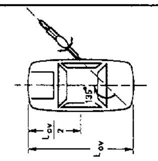
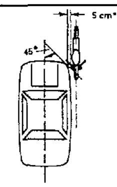
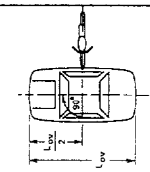
The results of the crash tests supplied by BMW AG as well as the computer simulations show that the respective load limits were fallen short of.

**Table 3.**
**Survey of BMW AG's *tests***

| Realised accident constellations by the BMW AG | Tested vehicles | | |
|---|---|---|---|
| | C1 two-wheeler | | Motor-scooter |
| | Solo | With pillion | Solo |
| 90° side impact of the car | 1 | | 1 |
| Two-wheeler's 90° side impact | 1 | 1 | 1 |
| Oblique 45° front impact between car and two-wheeler | 1 | | |
| rear -end impact of the car (impact angle 0°) | 1 | | |
| rear -end impact of the car (impact angle 30°) | 1 | | |
| 90° frontal impact against rigid barrier | 1 | | |
| skidding test | 1 | | |
| tipping the two-wheeler from a standing position | 1 | | |

__Evaluation of crash test__ – after analysing the crash tests it can be expected that the C1 concept guarantees the rider a very high degree of passive safety. The measurements as well as the calculated values (HPC, for example) from the crash tests are predominantly low. They currently fall far below the admissible biomechanical load limits. A direct comparison of the C1 vehicle with a conventional motor-scooter in the same accident constellation resulted in mostly much lower strain for the C1 two-wheeler riders.

**Table 4:**
**Accident constellations according to ISO**

| Constellation 1 | Constellation 2 | Constellation 3 | Constellation 4 | Constellation 5 | Constellation 6 | Constellation 7 |
|---|---|---|---|---|---|---|
| $v_{Pkw}$=35 km/h<br>$v_{Krad}$=0 km/h | $v_{Pkw}$=24 km/h<br>$v_{Krad}$=48 km/h | $v_{Pkw}$=24 km/h<br>$v_{Krad}$=48 km/h | $v_{Pkw}$=24 km/h<br>$v_{Krad}$=48 km/h | $v_{Pkw}$=24 km/h<br>$v_{Krad}$=48 km/h | $v_{Pkw}$=0 km/h<br>$v_{Krad}$=48 km/h | $v_{Pkw}$=0 km/h<br>$v_{Krad}$=48 km/h |
|  |  |  |  |  |  |  |

With this, in a real accident situation not only lower frequencies of injury can be expected but also lessened injury seriousness, to the head above all.

In a frontal collision the C1 vehicle's driver is bound to the vehicle by the safety belts. For this reason there is no collision of the driver with the opposing vehicle's parts (roof frame, for example). This results in low head acceleration and low HPC values for the C1 vehicle's riders. The neck momentum is reduced about 50% compared to the neck momentum of the driver of a conventional two-wheeler. The neck force is of the same order in both two-wheel concepts. It should be noted that the Dummy on the C1 vehicle and also the dummy on the commercial two-wheeler wore helmets. Through the helmet, the mass of the head area is increased. If assumed that the same deceleration is effective as they do on unhelmeted riders, the resulting forces and moments (with the same lever-arm) are larger for a helmeted rider. If the helmet-wearing law were dropped, we would expect more minimal neck strain to the C1 vehicle rider. The chest and hip strain of the C1 rider are higher than in the rider of the conventional two-wheeler (due to safety belt support); they lie, however, below the biomechanically acceptable load limit. In collisions between conventional two-wheeler and cars, a large part of the rider's kinetic energy is reduced through primary head impact, for example on the edge of the roof of the opposing vehicle, and through leg contact with the handlebars or parts of the covering and therefore only a very small strain results in the hip and chest areas. By belting the C1 rider the load occurring during impact is distributed more evenly on the upper body. No knowledge is present on the load in the abdomen. It is, however, assumed that the relationship of abdomen load (C1 rider as opposed to the rider of a conventional two-wheeler) is similar to the relationship of the strains in the hip and chest area. The lower extremities experience very low strains (only about 1/12 of the strain of the rider of a conventional two-wheeler).

In a side impact the C1 vehicle is scooped onto the car hitting it. The rotation leads to an impact between the upper portion of the C1's frame structure and the front of the car. Through the roll bar, the fixing of the rider by belts and the protective bar on the side the rider is extensively protected from direct contact with large parts of the opposing vehicle. In this way it will generally come to very low strain. Similar to the frontal impact, the C1 rider's neck momentum is lower in comparison to the neck momentum of the driver of a conventional two-wheeler (about 70%). The neck forces are about of the same order in both two-wheel concepts. Chest load in the C1 rider are higher than the conventional two-wheeler driver's chest load. They lie, however, underneath the biomechanical load limits applicable for car riders. In a 90° hit from the side the strain in the hip area was measured at 60.5 g. Legislation in the USA prescribes a hip load limit of less than 90 g or 130 g for a car collision from the side. Through the slightly higher sitting position of the C1 rider as compared to conventional two-wheeler there is no direct impact between the front of the car and the hips. After the first contact between the car and the C1 vehicle it is accelerated to the side. Since a connection free of relative movements between the C1 vehicle and the rider is not possible, the rider remains in its original place because of inertia. Since the protective bar in the seat area limits the rider's sideways freedom, in the collision sequence the hip impacts the protective bar which results in the slightly raised hip load. The test shows very low hip load in tests with conventional motor-scooters. These can be explained in that the driver and vehicle in the conventional two-wheeler in comparison with the C1 vehicle are not tightly bound to each other and that the driver scooped and the vehicle pushed away on impact. Here there is a more grazing impact between the front of the vehicle and the hip of the rider.

The primary impact in the lower extremity area has relatively minor consequences since the extremities can avoid the side of impact. In this way the risk of lengthy, cost intensive leg injuries occurring which additionally can often lead to a reduction of earning capacity is reduced. By the scooping the driver to the side, it often comes to a helmeted head-impact with parts of the opposing vehicle. In part, considerable head loads occur on the two-wheel passengers. In the C1 vehicle, the safety cage which is formed by the roll bar works against that. Through the C1 vehicle conception, driver and vehicle don't separate during the collision, that way loads in the upper extremities are possible (through jamming between the frame structure and the collision opponent). In general these dangers can be avoided through appropriate measures (for example, padding the roll bars and increasing the tube cross sections of the roll bar).

After the primary impact the post crash phase follows. It is characterised by the tipping over of the two-wheel vehicle, swerving motions and/or secondary impacts. If the C1 vehicle tips over head contact with the street could occur if the roll bar safety zone is not wide enough. If the rider were not helmeted it could lead to extensive injuries in the head area. In crash tests no head impact on the road was determined. Only minor head strains appeared there. In connection with this the transferability of the dummy's behaviour to human beings must be questioned. An estimate on this subject is presented in the section "Estimating the sideways head movement of a C1 rider" which takes into consideration that people are considerably more flexible than a test dummy. For objective evaluation of the C1's safety potential a test procedure was developed, in co-operation with BMW AG and BASt, that is presented in detail in APPENDIX II.

Swerving motions in the C1 vehicle can lead to the rider's extremities leaving the protective area of the C1 vehicle. Since these movements cannot be prevented through constructive measures, precautions are to be made that reduce the injuries (for example padding the roll bars and/or increasing the tube cross sections of the roll bar). No definitive statements can be made based on video recordings on the secondary impact of a swerving or skidding C1 vehicle. It is, however, assumed that a possible secondary impact only leads to small rider strains – smaller than a conventional two-wheeler – since the C1 vehicle has a very stiff frame structure. To evaluate the frame structure, a testing procedure was developed (roof crush resistance test) which is based on FMVSS 216 and is described in APPENDIX III.

It can come to strong structural frame distortions or impacts in all collision phases of which the possible effect is that the windshield will break in the rider's protective area. BMW AG is planning according to the current specs for the shield to be merely tempered safety glass which can, in case of breakage, disintegrate into very small pieces. If no closed helmet is worn, the resulting splinters could penetrate the driver's eyes and cause serious eye injuries. For this reason BASt recommends the use of shields that meet the requirements of the European Parliament's and the Council's regulation 97/24/EC from June 17, 1997, chapter 12: "Windshields, windshield wipers,..." according to which the fragments and splinters after the glass breaks should be of such type that the risk of injury is kept to a minimum.

**Evaluation of simulation results** – Computer simulations for head loads were carried out for all 7 accident constellations required according to ISO 13232. The calculations were done for the C1 two-wheeler for a rider without a helmet, for the C1 two-wheeler with a rider with helmet and a typical motor-scooter with a rider wear a helmet. The HPC, the head acceleration and the GAMBIT were determined. The probability of brain injuries resulting from linear acceleration and rotational acceleration is calculated with the GAMBIT.

The results show that the HPC, the head acceleration and the GAMBIT all show clearly smaller values for a helmeted rider on a C1 vehicle than for a typical motor-scooter with a helmeted rider. In test constellation 6 in which a grazing frontal impact between the two-wheeler and a car occurs, head loads for the C1 rider are larger than those for a common cyclist, but they are nevertheless lower than the biomechanical load limit. In all, the higher safety potential of the C1 vehicle compared to a typical two-wheeler is clear. A comparison of loads between helmeted and non-helmeted C1 drivers in tests according to ISO (ISO 13232, 1995) only shows small differences. Head acceleration in test constellation IV (oblique impact of the C1 vehicle with an angle of 45° into the side of a car) is clearly higher for the C1 driver with a helmet than for the C1 driver without a helmet. The differences in the strains for the C1 driver with helmet and the typical motor-scooter's driver with helmet are to be searched for in the different movement behaviours during the collision and in the post crash phase.

In a commercial motor-scooter, during impact the driver and the vehicle separate whereby high loads (HPC>1000 for example) probably develop through direct impacts with the object collided into or obstacles. The head loads resulting from the C1 two-wheel driver's simulations cannot be concluded for impacts with collision opponent, one's own vehicle or with obstacles.

**Estimating the sideways head movement of a C1 rider**– The test evaluations described above have shown that only small C1 rider loads occur in primary collisions. It seems, on the other hand, that the C1 two-wheeler's swerving movements are, as just mentioned, problematic. Since the crash films and simulation results only deliver little information for evaluating head movement in the swerving phase, high speed recordings of BASt's side crash tests were evaluated. In addition, an estimation of human head movement as opposed to a dummy as the rider of a C1 two-wheeler was undertaken. Side impact tests carry out in the BASt analysed here, a barrier with an impact speed of 50 km/h drove rectangular into the side of the vehicle to be tested. On the impact side the vehicles were occupied with EUROSID dummies. The evaluation showed that the dummy's head stuck out an average of approx. 40 mm over its pressed-in shoulder during the impact. With a safety bar width of 20 to 25 mm at shoulder height it could lead to the head leaving the C1 vehicle's protection space.

In the post crash phase, considerably lower side impact speeds occur than in the previously named tests. High speeds are to be expected if the two-wheeler falls from its upright driving position. In order to estimate the impact speeds of a head on the street it is assumed that the head's centre of gravity in an upright sitting position is located at a height of 1.3 m to 1.5 m. In order to make an estimate by approximation, the driver's and the C1 vehicle's inertial momentum are not considered. In this assumption the whole potential energy of the head is transformed into translational kinetic energy and the result is, according to the beginning height of the head's centre of gravity, the head's speeds upon impact onto the road of 5.1 m/s to 5.4 m/s (18.1 km/h to 19.4 km/h).

In a study on further development of a special dummy's neck (APROD) (HUE et al., 1982), investigations on the head-neck area's flexibility in dummies and in corpses during impacts on the side were carried out. The impact speed in these experiments was 22 km/h, corresponding to the approximate speed level of a C1 rider's head upon impact on the road after falling from a standing position. In the experiments the head bending angle ($\alpha$) and the neck bending angle ($\beta$) were determined (see figure 3, APPENDIX I).

In order to carry out a rough calculation of the head's displacement to the side of an EUROSID dummy and human beings, the body dimensions required for calculation were taken from the EUROSID. The dimensions were taken over for the human being and are, together with the calculations of the results described in the following, put together in APPENDIX I. The head-neck system from the dummy as well as from the human being must also be displaced at least a half of a shoulder-width to the side in order for head contact with vehicle parts or obstacles near the shoulder to occur. Half of a shoulder-length is approx. 241 mm for an EUROSID. The calculation of sideways displacement of the head-neck system in an EUROSID, on the basis of test results for a dummy according to HUE et al., 1982 showed that this is displaced 217 mm at an impact speed of 22 km/h. If you continue the calculation on the basis of the test results for a person, it results in a sideways displacement of 274 mm in the head-neck system according to HUE et al., 1982. This shows people's higher flexibility as opposed to a dummy. The excess on the side of the head for the dummy is -24 mm (that means the head get not sideways beyond the shoulder) and 33 mm for the person (that means the head would be displaced sideways beyond the shoulder). These results show that tipping a C1 vehicle over occupied by a dummy produces no high loads, for example through impact on the street. Under the same testing conditions a human being would surely leave the C1 driver's protective space if it were only as wide as the driver's shoulders and it would result in contact with the road. Since the estimate of the sideways displacement of a person's head-neck system is just a rough calculation, BASt recommends constructing the protective space as well as the matching with the belt system so that even with a sideways displacement of the head of 50 mm beyond the side of the shoulder area no obstacle contact (the road for example) can occur.

To realise this request a test procedure was developed through co-operation between BMW AG and BASt. This procedure defined as a effectively requirement allows other constructive solutions in future developments. The detailed description of this test procedure can be found in APPENDIX II.

The buckling-up of the driver is a necessary condition for fulfilling this test procedure and for safe rider restraining. In order to prevent carelessness (forgetting, for example!) regarding buckling-up, a signal lamp was suggested according to BASt's opinion. This should be easily visible, shine with an appropriate intensity, and if necessary make the driver aware of the omitted buckling-up through blinking. From a behavioural science point of view a warning tone as a signal for an open belt is not agreed to since it unnecessarily causes noise stress and, as a result, could possibly have a negative influence on traffic. The light signal is not appropriate to prevent deliberate omission of seatbelt use.

## GENERAL REQUIREMENTS OF THE C1 VEHICLES OR COMPARABLE VEHICLE CONCEPTS

Since the C1 vehicle is a new type of two-wheel concept the necessity arises of defining general requirements that the vehicles of this conceptional group should fulfil. In this section the requirements of passive safety for such vehicles especially regarding head protection will be presented from the BASt's point of view. These requirements were derived from the evaluation of the C1 two-wheeler concept. The concern is to define the general requirements so that a high safety standard for this type of vehicle can be reached through their fulfilment. In this way it should be possible to evaluate future developments from other vehicle manufacturers concerning their passive safety potential and to recognise products that do not meet the required safety levels and keep them away from the market. Because of the requirements presented here the Ministry for Transport (BMV) formulated an ordinance concerning exemption from the obligation to wear a helmet.

- The following accident constellations were recommended by the BASt for evaluating the passive safety of such two-wheel concepts:
  Accident constellations from ISO 13232 (see table 4):

  - Constellation 1: 90° side impact of the car
  - Constellation 2: oblique 45° front impact between two-wheeler and car
  - Constellation 4: two-wheeler's oblique (45°) impact into the car side from behind
  - Constellation 6: grazing frontal impact between car and two-wheeler
  - Constellation 7: 90° impact on the side by the two-wheeler against a standing car

  Constellation 3 is covered through constellations 4 and 7 and constellation 5 is comparable with constellation 2.

  In addition there are:

  - a sideways tipping test and
  - a roof crush resistance test

to be carried out. The respective test description and implementation is presented in APPENDIX II and APPENDIX III.

- In all of the previously described tests the load limit for rider head is HPC=1000 according to the requirements in the frontal and side impact tests for cars.
- The rider's extremities can leave the vehicle's safety area in the impact or swerving phases. In order to keep injuries to the extremities by being jammed in by one's own vehicle as minimal as possible, contact forces (surface pressures) are to be kept as minimal as possible. If the requirement of the regulation 97/24/EC of the European Parliament and the Council from June 17, 1997 on components and characteristics of two and three-wheeled motorised vehicles, chapter 3, cannot be fulfilled, padding is to be installed in the extremities' contact areas.
- The two-wheeler has to be equipped with an appropriate, state-of-the-art restraint system which meets the requirement of the regulation 97/24/EC of the European Parliament and the Council from June 17, 1997 on components and characteristics of two and three-wheeled motorised vehicles (chapter 11, Anchoring safety belts and safety belts on small three-wheeled motorcycles, three and four-wheeled vehicles with body constructions). The restraint system must safely restrain the rider in all phases of a possible accident and thereby protect him/her from contact with obstacles and/or parts of his/her own vehicle's structure.
- If the two-wheeler's protection area is foreseen with windows, they must meet the requirements of the regulation 97/24/EC of the European Parliament and the Council from June 17, 1997 on components and characteristics of two and three-wheeled motorised vehicles, chapter 12, appendix I, section 1.1. or 1.2..
- If a restraint system is foreseen for the vehicle's rider and it is to be manually operated, the installation of a signal lamp is required in order to prevent carelessness during use (forgetting, for example!). This lamp should be placed where it is easily visible, shine with appropriate intensity and meet the requirements of the EEC regulation 78/316, appendix III, figure 9. An informational sign must be within field of view of the prepared driver on which it is pointed out that the obligation to wear a helmet exists if the rider does not put on the belt system.

## INVESTIGATIVE SUGGESTION FOR OBSERVING MARKET AND ACCIDENT EVENTS

It is possible that vehicles in this new class will reach a certain market share in the future and are to be found frequently, especially in city traffic. It must remain to be seen how this new class of vehicles will reflect in accident events since no experiences exist regarding this. For this reason it is being suggested to carry out an accompanying investigation regarding market development and accident events in the coming years parallel to the introduction of this new type of two-wheeler concept into the market. This investigation should be set up long term since market penetration at the beginning of the series' introduction will be very small. Information on market development can be expected from the vehicle manufacturers and importers. The accident event can take place through special evaluations at the Medical University of Hanover. According to a statement by BMW AG, the company will also investigate C1 accident behaviour in the future within the framework of its own accident inquiries of BMW vehicles in the Munich area.

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## APPENDIX 1 – ESTIMATION OF SIDEWAYS HEAD-NECK DISPLACEMENT

According to (HUE et al., 1982) the following head bending angles (α) and neck bending angles (β) were determined at an impact speed of 22 km/h:

| | α | β |
|---|---|---|
| Dummy | 61 | 48 |
| Corpse | 72 | 108 |

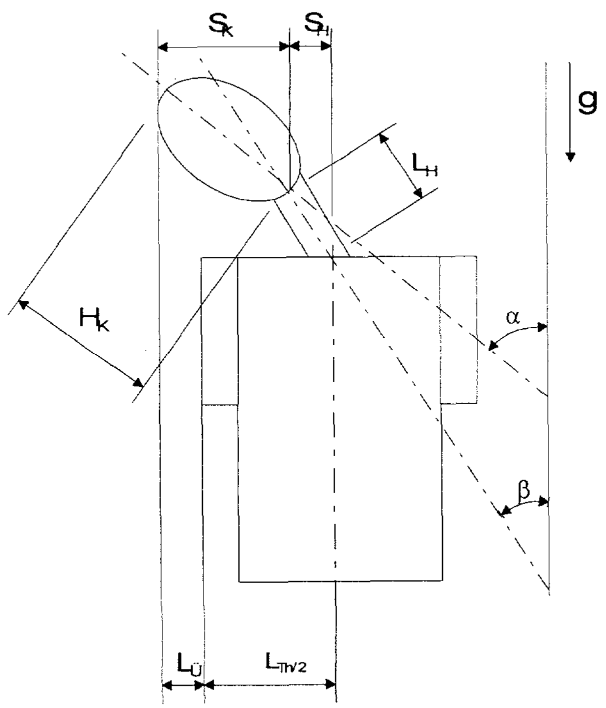


**Figure 3: Geometric connections in the head-neck system during impact from the side and modified according to HUE et al., 1982**

Values searched for:

- sideways displacement of the neck: $S_H$
- sideways displacement of the head: $S_K$
- sideways displacement of the head-neck system: $S_\Sigma$
- sideways excess of the head over the shoulder: $L_Ü$

For calculating of the required EUROSID dimensions:

| Description | Formula sign | Dimension |
|---|---|---|
| Half width of the upper body in the shoulder area | $L_{Th/2}$ | 241mm |
| Neck length | $L_H$ | 146mm |
| Head height | $H_K$ | 143mm |

The equations for calculating the desired $S_H$ and $S_K$ sizes can be derived from the angular relationships in figure 3's geometry.

Calculation $S_H$: $$\sin\beta = \frac{S_H}{L_H} \Rightarrow S_H = \sin\beta \cdot L_H$$

| | Dummy | Human being |
|---|---|---|
| $S_H$ | 100 mm | 145 mm |

Calculation $S_K$: $$\sin\alpha = \frac{S_K}{H_K} \Rightarrow S_K = \sin\alpha \cdot H_K$$

| | Dummy | Human being |
|---|---|---|
| $S_K$ | 117 mm | 129 mm |

The total sideways displacement of the head-neck system ($S_\Sigma$) can be calculated from the sum of the head's sideways displacement and the sideways neck displacement.

Calculation of $S_\Sigma$: $$S_\Sigma = S_H + S_K$$

| | Dummy | Human being |
|---|---|---|
| $S_\Sigma$ | 217 mm | 274 mm |

The head excess on the side over the shoulder ($L_Ü$) results from the relationship of the half of the width of the upper body in the shoulder area ($L_{TW2}$) with the whole sideways displacement of the head-neck system ($S_\Sigma$).

Calculation of $L_Ü$: $L_Ü = S_\Sigma - S_{Th/2}$

| | Dummy | Human being |
|---|---|---|
| $L_Ü$ | -24,0 mm | 33,0 mm |

If you now imagine that the person hits the street sideways, for example, then negative side excess means that no contact with the road occurred. A positive $L_ü$ would mean the head touched the street.

## APPENDIX II – SIDE TIPPING TEST

### 1. Area of use

In this test it is being investigated whether head contact between rider and road occurred while tipping the vehicle occupied with a driver.

### 2. Requirements

When the test-vehicle falls to the side, the EUROSID (corresponding to regulation 96/27/EC from May 20, 1996 on the protection of motorised vehicle passengers in a crash on the side) dummy's head speed must amount to 20 km/h + 2 km/h.

Thereby one of the points listed below must be fulfilled.

#### 2.1. Distance from the head to the road

The distance between the head and the road may not touch the distance plate defined in 3.3.1.. There may not be any coloured markings visible on the head.

#### 2.2. Protective devices for the head

Head load criteria HPC<1000 applies during use of protective devices for the head that prevent immediate contact with the ground.

### 3. Test set-up

#### 3.1. Vehicle

Possibilities:

a) The testing vehicle either stands with both wheels on a horizontal, even, clean surface which is representative of a normal, dry, non-dirtied street surface (called "ground" in the following) or if need be on a raised platform set up parallel to this surface.

b) The vehicle will be hung up parallel to the ground with contact surface defined under 4.1..

The front wheel is found in the straight position. The wheels can be blocked through using or intervention in the brake system during the test.

If the handlebars project out from the contact surface it must be removed for the test or changed so that ground contact is avoided.

Adjustable seats and head-rests are be brought to their middle positions.

#### 3.2. Dummy

An EUROSID dummy will be used as a test dummy. It is to be positioned in the middle of the longitudinal centre plane of the vehicle.

The legs are to be put down in the normal driving position.

The belt(s) are put on with the least possible belt slack.

The upper arms are adjusted at a 45° angle to the vertical upper body.

#### 3.3. Measuring equipment

##### 3.3.1. Determination of the head-ground distance

To determine the distance between head and contact level (according to 2.1.) a $75^{+2}_{-0}$ mm thick plate (distance plate) with appropriate dimensions placed on the ground so that before and during touching the vehicle's structure in the required contact level no contact with other body parts as the head and/or vehicle parts are possible.

The distance plate is coloured on the top part before the test.

When the head touches the plate, the coloured markings must build up paint marks.

##### 3.3.2. Head load value determination

The head acceleration values from EUROSID are measured and evaluated (HPC, for example) in the test in 2.2..

##### 3.3.3. Determination of maximum head speed

The process of determining head speed is not fixed yet. Possible procedures: the evaluation of a high-speed film recording or the integration of acceleration in the y-direction.

4. Test implementation

4.1. Process

A contact level will be defined as a touching surface for the vehicle's side and the ground for the testing procedure. The touch level resulting from the dynamics of the test according to 3.1.a) between the vehicle's side and a flat surface by which the head distance to the surface is the smallest is set as the contact level.

a) The vehicle tips from a standing position (vertical position) onto the foreseen side so that the contact level touched the ground.

b) The vehicle falls, aligned according to 3.1.b), to the ground from a height given through the requirement in 4.2.

4.2. Head speed

The maximum head speed in test procedures a) and b) should amount to 20 km/h +2 km/h.

In order to reach this speed it could be necessary in test 4.1.a), because of the design, to tip the vehicle from an elevated position (see 3.1.a)).

In test constellation 4.1.b) the necessary fall height corresponding to the impact speed of 20 km/h +2 km/h is to be determined.

5. Documentation

High speed film recordings from the head's impact area serve to document the sequence of movements.

## APPENDIX III – ROOF CRUSH RESISTANCE TEST

1. Area of use

The procedure serves to check stiffness of roof frames and roof structures on single-track vehicles with belt systems for which an exemption from the obligation to wear a helmet is being striven.

2. Requirements

The maximum power that may appear during a 127 mm deformation distance is at least 22,2 kN during the roof crush resistance test of single-track vehicles with a belt system that are striving for exemption from the obligation to wear a helmet.

The energy absorbed during the roof structure's deformation must at least be 1.4 kJ. (This level meets a linear rise in power from 0 to 22.2 kN over a deformation distance of 127 mm – see figure 5) Very stiff roof constructions that collapse after very minimal deforming cannot fulfil these requirements.

3. Test set-up of the roof crush resistance test

3.1. Vehicle

The vehicle's frame with the roof structure is fixed on a flat, stable base plate so that it cannot be shifted during the test (see figure 4).

The vehicle's frame must be in a normal position relative to the base for this and supported so that a fixed point in the frame in the immediate vicinity of the vehicle's centre of gravity and the slant of the main frame remain nearly unchanged during the test (±10 mm, ±3°).

All supports must lie under a parallel level to the base plate through the H-point. For adjustable seats, the H-point from the lowest seat position applies.

Above this level there may be no additional reinforcement attached except for structural ones that are designed as supporting elements for the respective vehicle (for example: motor, bucket seat or body).

3.2. Pressure plate

With a flat, large enough plate (larger than the contact surface of the whole roof structure after deformation) the roof structure is pressed parallel to the base plate with constant speed (see figure 4).

4. Test implementation

The pressure plate is moved with a maximum speed of 0.013 m/s until a deformation of 127 mm. The maximum test time is 120 s.

5. Documentation

The force-travel-characteristic (vertical to the pressure plate) will be recorded for documentation of the force course (see figure 5).

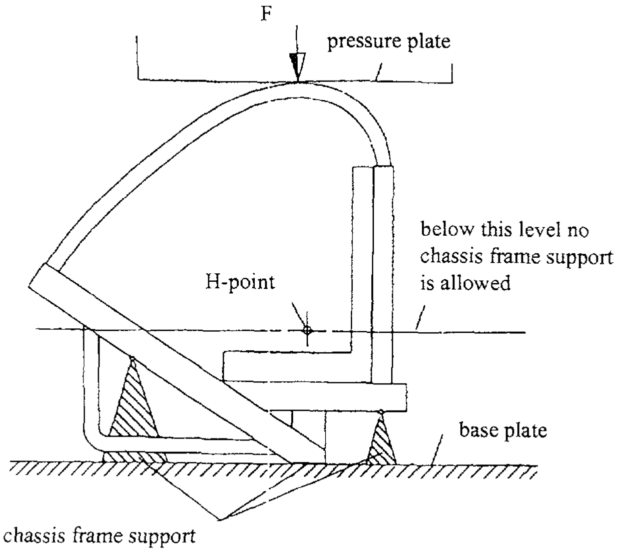


**Figure 4: Test set-up**

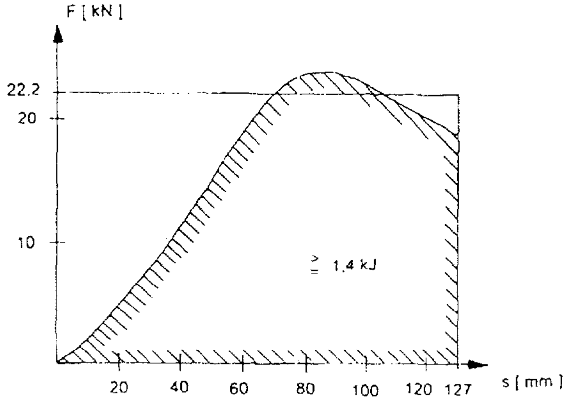


**Figure 5: Force-travel diagram**