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Compact accident research

Safety Aspects of High-Speed Pedelecs

Unfallforschung der Versicherer

GDV

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Introduction

Electric-assist bicycles (pedelecs) are becoming increasingly popular in Germany. According to the German two-wheeler industry association Zweirad-Industrie-Verband (ZIV), around 150,000 of these bicycles were sold in 2009 [1]. 200,000 were sold in 2010, and the association expects 300,000 to be sold in 2011. The percentage of sales accounted for high-speed pedelecs is now in the upper single-digit range. The market for retrofit kits is also growing, according to the ZIV. 10,000 of these were sold in 2010. Around 10 % of these sales were for high-speed pedelecs.

This trend also brings with it dangers, however. In order to be able to better assess these new vehicles and identify possible threats to safety, the UDV (German Insurers Accident Research) commissioned DEKRA to carry out extensive investigations. These consisted of analyzing construction regulations, operational safety and riding and crash tests. The investigations focused on high-speed pedelecs, where pedaling is assisted by motor input up to a speed of 45 km/h.

Content

1 Construction regulations

There used to be a clear distinction between bicycles and mopeds. Now, however, we are seeing intelligent combinations of the two. They are known as pedelecs (pedal electric cycles), e-bikes, LEVs (light electric vehicles) or electric bikes. Electric bikes are bicycles that also have an electric motor. The type of motor assistance used has consequences in terms of both vehicle registration and license requirements.

There are two groups of pedelecs. A critical criterion used to distinguish between them is the maximum speed at which the cyclist still receives assistance from the electric motor. For conventional pedelecs, which are the most widely available type, this speed is 25 km/h. For high-speed pedelecs it is 45 km/h. European Directive 2002/24/EC defines a slow pedelec as follows [2]: „cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of 0.25 kW, of which the output is progressively reduced and finally cut off as the vehicle reaches a speed of 25 km/h, or sooner, if the cyclist stops pedaling."

In the opinion of the UDV, high-speed pedelecs (up to 45 km/h) must be viewed in the same way as a moped (category L1e), as defined by European Directive 2002/24/EC, and all the technical consequences of that must therefore be taken into account. That means, for example, that a type approval is required, insurance is mandatory (evidence of insurance must thus be displayed on the vehicle), and a moped driving license is required. In addition, they must be ridden on the road, and the rider is required to wear a suitable protective helmet pursuant to section 21a of the German road traffic regulations (StVO). That means a motorcycle helmet in this case. The technical systems must meet the requirements of the Directives specified in the above EU Directive. For example, the braking system must comply with 93/14/EC (2006/27/EC), the lighting and light-signaling devices with 2009/67/EC, tires and their fitting with 97/24/EC Chapter 1 and rear-view mirrors with 97/24/EC Chapter 4 (see table 1).

The high-speed pedelecs currently on the market do not meet these requirements. This is now the subject of intense debate among experts and politicians.

It is important to maintain a sense of proportion in this context. It would make sense to create a new vehicle category for high-speed pedelecs with rules and regulations with regard to both technical and type approval aspects (e.g. maximum speed of 35 km/h, maximum continuous rated power of 500 W, insurance sticker, moped test certificate, bicycle helmet and bell instead of horn).

Table 1:
Overview of the individual Directives with which mopeds of category L1e are required to comply, according to Directive 2002/24/EC [2].

Topic	Directive
Braking systems	93/14/EWG
Identification of controls	2009/80/EG
Audible warning devices	93/30/EWG
Stands	2009/78/EG
Passenger hand-holds on two-wheel vehicles	2009/79/EG
Devices to prevent unauthorised use of the vehicle	93/33/EWG
Statutory markings	93/34/EWG
Installation of lighting and light-signaling devices on the vehicle	2009/67/EG
Masses and dimensions	93/93/EWG
Space for mounting the rear registration plate	2009/62/EG
Maximum design speed, maximum torque and maximum net engine power, adapting to technical progress Directive 95/1/EC	2002/41/EG
Certain components and characteristics	97/24/EG
Tires and their fitting	97/24/EG Kap. 1
Component type-approval of a type of lighting and light-signaling device	97/24/EG Kap. 2
External projections	97/24/EG Kap. 3
Rear-view mirrors	97/24/EG Kap. 4
Measures to be taken against air pollution	97/24/EG Kap. 5
Fuel tanks	97/24/EG Kap. 6
Anti-tampering measures	97/24/EG Kap. 7
Electromagnetic compatibility	97/24/EG Kap. 8
Permissible sound levels and exhaust systems	97/24/EG Kap. 9
Trailer coupling devices	97/24/EG Kap. 10
Safety-belt anchorages and safety belts	97/24/EG Kap. 11
Glazing, windscreen wipers, washers, de-icers and de-misters	97/24/EG Kap. 12
Speedometers	2000/7/EG

2 Vehicles investigated

Six pedelecs of different manufacturers were included in the investigation (see table 2). Consequently, they had different drive systems, frames and other technical features. It is clearly not possible to paint a complete picture of the risks of all of the vehicles available on the market in this way. But it does permit an initial assessment to be made of this new vehicle category.

Table 2:
Overview of the pedelecs investigated

Sachs Elektra 3

Assistance up to	45 km / h depending on transmission
Motor	350 W front-wheel hub motor with speed sensor
Brakes	Mechanical V-rimbrake and coaster brake
Weight Empty/battery	29,9 kg / 3,5 kg
GVWR	150 kg

Diamant Zuoma Supreme+

Assistance up to	30 km / h
Motor	250 W rear-wheel hub motor with torque sensor
Brakes	Hydraulic rim brake
Weight Emtpy/battery	21,6 kg / 3,0 kg
GVWR	130 kg

Raleigh Cityliner

Assistance up to	25 km / h depending on transmission
Motor	250 W crank-drive motor with torque sensor
Brakes	Mechanical V-rimbrake
Weight Empty/battery	29,9 kg / 3,5 kg
GVWR	150 kg

Flyer S Series

Assistance up to	45 km / h depending on transmission
Motor	250 W crank-drive motor with torque sensor
Brakes	Hydraulic disc brake
Weight Emty/batteriy	19 - 22 kg / 2,6 kg
GVWR	149 kg

Flyer X Series

Assistance up to	36 km / h
Motor	300 W crank-drive motor with torque sensor
Brakes	Hydraulic disc brake
Weight Empty/battery	22 - 24 kg / ca. 3 kg
GVWR	149 kg

Excelsior Alu City

Assistance up to	45 km / h depending on transmission
Motor	180 W front-wheel hub motor with speed sensor
Brakes	Mechanical V-rimbrake and coaster brake
Weight Empty/battery	24 kg / 1,1 kg
GVWR	140 kg

3 Operational safety

The electrical system was tested based on ECE-R100-01. It was found that the vehicles investigated did not represent a problem in terms of electric shock, since the components operate in the low-voltage range. All voltages obtained were lower than 60 V. A short circuit in the motor can merely lead to critical blocking of the front or rear wheel in the case of hub motors without free running (e.g. through the recuperation function). The batteries analyzed in the test were found to be adequately encapsulated and securely in place. Improper retrofitting can, however, result in dangers. These can have an impact on the safety of the vehicle. Simple attached parts can damage the cables of the electrical system.

It also became clear that safety standards are lower for vehicles in the lower price categories with regard to the drive concept in general, the electronic battery monitoring system and, in particular, the cable routing.

4 Technical testing and manipulation

Technical aspects were examined based on European Directive 2002/24/EC. The brake systems of the selected pedelecs were thus examined based on Directive 93/14/EC (2006/27/EC). All brakes performed adequately on a dry road surface. On a wet road surface, however, there were great differences in braking performance. The mechanical rim brakes, in particular, did not perform well in wet conditions, as shown in figure 1 below.

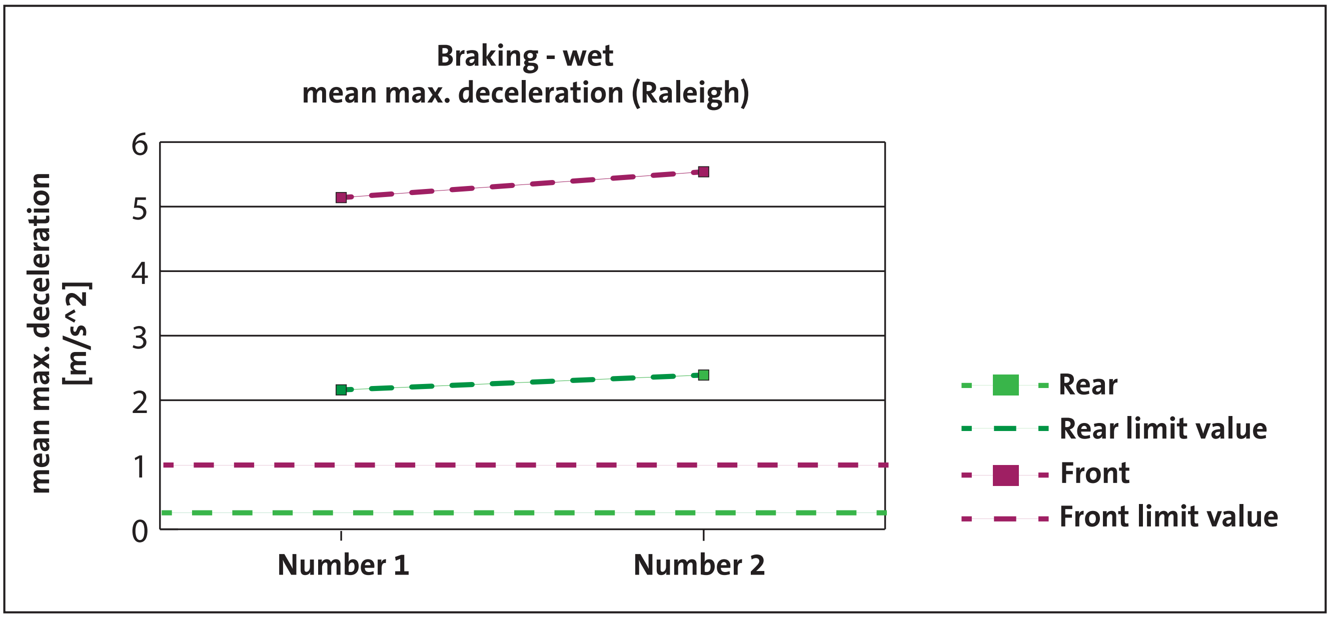
Hydraulic rim brakes showed better braking performance. The hydraulic disc brake system performed best and complied with the required threshold values for braking distance and fully developed deceleration. However, there is a danger of overbraking at the front wheel when the brake is operated suddenly and forcefully.

The braking performance of pedelec and trailer combinations was also evaluated. The combination of a powered bicycle with a trailer for a child can represent an attractive option for families. The investigations showed that trailers with overrun brakes had a better braking performance and are therefore to be preferred. Given the current situation, namely that high-speed pedelecs are considered to be category L1e vehicles, this means the loaded trailer must not weigh more than half the unladen weight of the towing vehicle, which prevents the use of trailers to transport children. There is no such restriction on slower pedelecs because they are classified as bicycles.

The different drive concepts also exhibit different and, in some cases, critical characteristics in operation. In particular, the hub motor on the front wheel was found to be a less favorable combination. On wet surfaces and/or in bends, in particular, critical situations can occur as a result of the sudden activation of pedal assistance or skidding of the front wheel. With some drive concepts, motor assistance continued for a short time when the brakes were applied or on a downhill stretch, resulting in critical situations.

Manipulation

Pedelecs are also susceptible to tampering. In particular, people may aim to increase the maximum speed attainable with motor assistance. Distinctions are drawn between mechanical, electrical and electronic tampering. All three kinds of tampering are possible with the pedelecs that are currently available. Simply by replacing the drive pinion of a pedelec



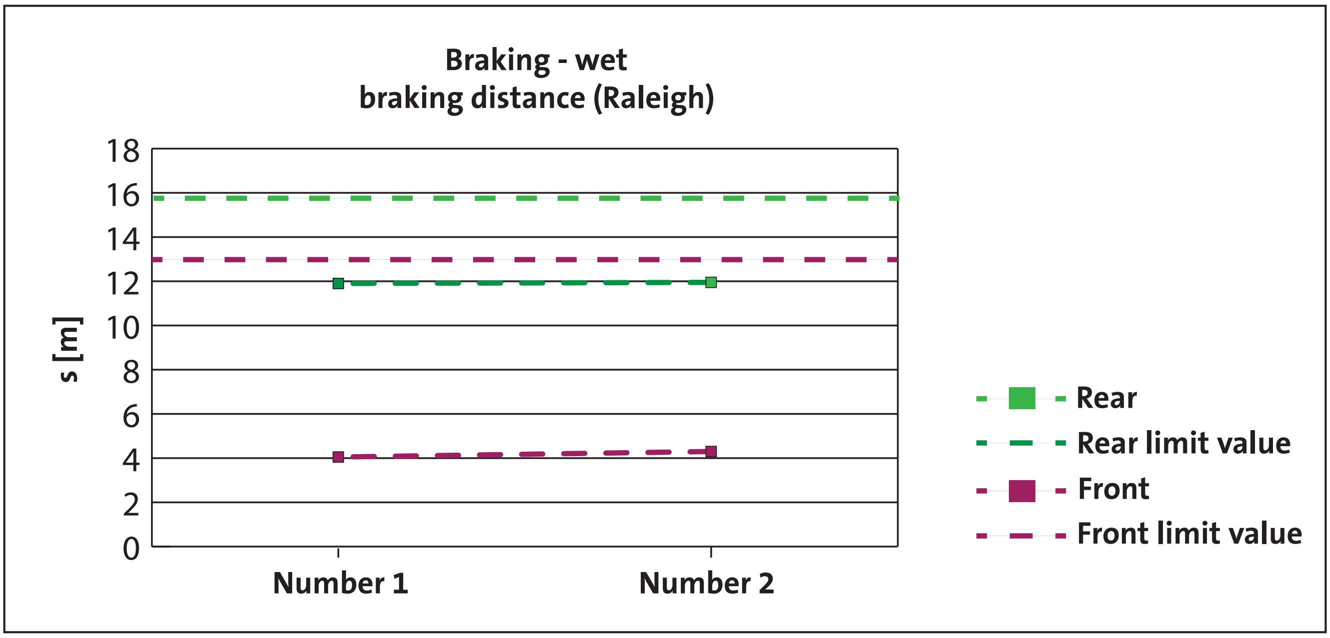


Figure 1:
Deceleration and braking distances for the Raleigh Cityliner with mechanical rim brakes

with a crank-drive motor and thus altering the transmission ratio, for example, it was possible to increase the maximum speed achievable with motor assistance by 20 %. Furthermore, it was possible to show that the maximum speed can be tampered with very easily electronically by entering a special key combination on the control unit. Pedelecs generally do not have an anti-tampering control plate of the type required by Directive 2002/24/EC [2]. It is thus not possible to see, for example, what motor or battery type the vehicle has. The user thus has scope for all kinds of tampering. An anti-tampering control plate would provide a better overview and allow the vehicle's equipment level to be checked.

5 Crash tests and rides in the city

Leaving aside the technical aspects, the use of pedelecs represents an additional risk on the roads. Not only do pedelecs have a high average and maximum speed, they also have a high mileage. This applies not just in flat areas but in hilly areas as well. As a result of the changing conditions, more critical situations or accidents and thus more casualties are to be feared.

More frequent overtaking maneuvers are inevitable, for example. As a result of the high speeds of these vehicles, the consequences of accidents are likely to be serious for both cyclists and pedelec riders. Pedestrians are the most vulnerable road users. If pedelecs are used on paths or sidewalks or paths designed for both pedestrians and cyclists, collisions can result in serious injuries for all involved.

Pedelecs appeal to many groups of cyclists: senior citizens, parents (with trailers for children) and even cyclists who are fit and like to take a lot of exercise. For car drivers it will be more difficult in future to see how fast a cyclist is riding. With electric motor assistance, a senior citizen on a city bike can now ride much faster than you would expect from previous experience. This can result in hazardous situations at exits and intersections. It is not just pedelec riders without a helmet who will suffer serious injuries in side impact collisions with cars.

Crash tests

Crash tests were carried out that represent the typical everyday situations on the roads described. They differ from conventional everyday situations involving bicycles only in terms of the higher collision speeds and greater weights of the pedelecs involved. The dangerousness of such situations for those involved was illustrated by means of the values recorded for the crash dummies. These findings can also be applied to cyclists.

The first test involved an overtaking maneuver. A pedelec traveling at 44 km/h overtook a bicycle traveling at 22 km/h with an overlap of 0.2 m (see figure 2). Both the pedelec and the bicycle were ridden by a Hybrid III dummy with instrumentation. The forces to which the head and neck of the pedelec dummy were subjected exceeded the limit values, which were selected based on ECE-R 94/95. The neck and chest of the dummy on the bicycle were subjected to very high forces.

Figure 2:
Collision between a bicycle (at 22 km/h) and an overtaking pedelec (at 44 km/h).

In the second test, the pedelec hit the middle of the passenger‘s door of a stationary car at a speed of 44 km/h and an angle of 90 degrees (see figure 3). A Hybrid III dummy with instrumentation was on the pedelec. The values measured indicated that the head, neck and chest were subject to very high forces that resulted in the limit values for the neck bending moment and chest compression speed being exceeded.

Figure 3:
Collision between a stationary car and a pedelec coming from the side (at a speed of 44 km/h)

In the third test, a pedelec hit a standing pedestrian in the side at 25 km/h (see figure 4). The pedestrian was a Hybrid III dummy with a standing pelvis. The dummy on the pedelec was also a Hybrid III type. The limit values for head loading were exceeded on both dummies.

Figure 4:
Collision between pedelec (25 km/h) and pedestrian

City rides

City rides in Dresden with four people and four different pedelecs showed that in one case the average speed was 18.8 km/h compared to 14.9 km/h for a normal bicycle without motor assistance. In this case the maximum speeds ridden increased from 23.8 km/h to 35.5 km/h. The city center circuit used was approximately 5.05 km in length (see figure 5).

Figure 5:
The circuit used for the city rides in Dresden

All pedelec riders in the study behaved like cyclists. It is strongly to be suspected that inexperienced users of high-speed pedelecs will use cycle paths or sidewalks because they are uneasy about riding in dense traffic. And this is where the greatest potential for danger lies. It is essential to obtain more objective data on the behavior of pedelec riders on the roads.

6 Conclusion

Pedelecs have enjoyed great popularity for some time now. They are set to establish themselves on Germany‘s roads. High-speed pedelecs, in particular, represent a new risk that must not be underestimated. Even standard, slower pedelecs increase the maximum and average speeds of everyday riders. Most pedelec types are enjoyable to ride, and, not least because of this, their average mileage will be higher than that for bicycles. This combination of higher speeds and higher mileage means it is likely that there will be more accidents involving these vehicles in the future. Since pedelec riders are unprotected, the consequences of these accidents will be serious. It is important to explain the situation to road users and inform them about the new risks. In addition, the general legal position regarding pedelecs must quickly be clarified. This has a direct influence on the design of these vehicles. From a safety-related perspective, pedelecs should not be just bicycles with a battery and a motor. Instead, the increased forces to which riders are subjected and more extreme operating conditions mean that separate developments and technical solutions are required. Consequently, a very critical view should be taken of retrofitting conventional bicycles to convert them to pedelecs.

The crash test films can be seen at **www.youtube.com/unfallforschung**. There is more information available at **www.udv.de** in the section entitled „Vehicle safety“.

References

[1] Pardey, H. - H. (2011): „Die E-Mobilität findet bei uns statt.“ Frankfurter Allgemeine Zeitung, Technik und Motor, March 29, 2011, No. 74.

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