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CLASSIFICATION OF HAZARDS LEADING TO INJURIES TO THE LOWER PART OF THE LEG OF MOTORCYCLISTS IN A FUNCTION OF DESIGNING THE PROTECTIVE FEATURES OF BOOTS FOR OFF-ROAD MOTORCYCLE RIDING

Vladimir Lesnikov
SAT Media Group, Belgrade, Serbia
vlzemun@gmail.com

Abstract Off-road motorcycle boots have a special construction to provide protection against injuries. A survey among motorcycle riders showed that there are numerous risk factors leading to injuries to the foot, ankle and lower leg, and that injuries of various types and severity occur in practice. These hazards are classified into four basic groups. An analysis of off-road motorcycle boots shows that in terms of protection there are significant differences between models and that not all boots provide equally effective protection in all risk situations. The conducted analysis provides the basis for further improvement in the construction of motorcycling boots for the purpose of injury prevention.

Keywords: Motorcycle; off-road; boot; injury; safety; protection.

1. INTRODUCTION

Because of the risk of injury, boots intended for riding off-road motorcycles are made to provide a higher level of protection than, for example, boots intended for riding on asphalt. To what extent they fulfill the need for increased protection was analyzed in a pilot study that included a number of boot models for riding in the most difficult conditions. Such models are designated as boots for motocross and enduro riding, or off-road boots. They are used equally by racers and drivers who drive recreationally or for other reasons.

2. SURVEY OF MOTORCYCLE DRIVERS

In order to be able to conclude the extent to which motorcycle boots fulfill their role, it is first necessary to investigate the situations in which they should provide protection. In this regard, a survey was conducted among off-road motorcycle riders. The average age of the 15 surveyed motorcyclists was 45.73 years (standard deviation 9.50) and the average of their experience in off-road driving is 9.27 years (standard deviation 5.22). On average, drivers ride a motorcycle 32.60 days a year in off-road conditions (standard deviation 20.75).

The questions were related to risky situations and injuries to the foot, ankle and lower leg, and injuries were classified according to injury mechanism and severity. The analysis of the obtained data showed that risky situations can be classified into several groups, namely: impacts, pinching, bending and abrasion. These are basic hazards which cause injuries to the lower part of the legs of motorcyclists. Some data from the survey was also used in the assessment of the protective properties of boots.

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3. ANALYSIS OF MOTORCYCLE BOOTS

Based on the four aforementioned groups of danger, how well the boots protect against these risk factors was analyzed. The analysis included 16 models of boots intended for driving in the most difficult off-road conditions. Alpinestars, TCX, Gaerne, Forma, Sidi, Fox, Acerbis, Leatt, Scott and Bogotto boots were analyzed, mostly models from the upper half of the range.

Basically, all off-road motorcycle boots have a number of similar construction details. The basic material is some kind of artificial leather (usually called microfiber), and less often natural leather. The sole is very rigid, and the front part is covered to a considerable extent, or completely, with a plastic, which in some models is also present at the heel. Thinner plastic plates often cover a significant part of the lower leg and foot. A thicker plastic protector exists on the upper half of the boot, in front of the shin. Below that, in front of the ankle, there is a softer material with a thicker lining that cushions the impacts, and such a softer surface is also on the back side, above the heel. The role of these softer parts is to enable foot movement at the ankle, and on the front side, to enable the opening of the boot. More significant differences exist in the area of the ankle. Models with a more complex construction have joints at both sides of the ankle, that are connecting plastic covers of the lower leg and the foot (Figure 1). This joint ensures easier movement of the foot. Some models also have some kind of limiter, mostly above the heel (Figure 2), whose task is to prevent excessive flexion and extension of the ankle. Many of the analyzed boots meet the EN 13634 standard, which determines some protective properties of boots. In this research, the standard was not analyzed, but attention was paid to the features of current models of boots from the point of view of risky situations.

Figure 1. Boot with joint, without limiter.

The possibility of conducting tests to measure some physical properties of the boots was considered, but this was not done in this study as this pilot study did not aim to provide numerical results. Instead, it sought to preliminarily determine the properties of the boots, which would give qualitative guidelines for more detailed research in this direction. Not many articles in this field were found

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during the literature review process. There are a number of works, for example [5, 6], which are more often related to motorcycle riding on roads, much less off-road, and, with a few exceptions, mainly treat injuries statistically, without a deeper analysis of protective equipment.

Figure 2. Boot with joint and limiter.

4. RISKS AND PROTECTION AGAINST MOTORCYCLE RIDERS' LEG INJURIES

Since off-road motorcycle boots have largely similar features, the results of the analysis are given as summary ratings, which generally apply to all models. In the following, summary data will be described, which were obtained based on the analysis of boots, the conducted survey of motorcyclists and an insight into the literature.

4.1. Impact Protection

Impacts can occur both during falls and when driving, usually when the foot hits an obstacle, such as a branch, or when the front wheel lifts, for example, a stone that hits the boot.

In terms of impact protection, there is a difference in the degree of protection provided by different parts of the boots. As the strongest part of the boot, the sole protects well against impacts. Rigid plastic reinforcements protect the forefoot, and in many models also the heel. Less rigid plastic plates protect the lower leg and the lateral surfaces of the foot and ankle. In front of, and often behind, the ankle there is no plastic protection, but thicker soft material, so it could be assumed that there is an increased risk in those areas. However, the experiences of drivers do not show significant problems related to this risk. Because of the appropriate protection, and the fact that impacts in this region tend not to be intense, existing boots protect well against impacts in the vast majority of situations. However, rare cases of slightly more serious injuries have been recorded, and these cannot be ruled out, so there is room for improving the boots.

A special case of impact occurs when the driver suddenly leans on his leg, for example trying to prevent a fall. This can create an increased load on the foot that is transferred to the ankle and knee.

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Apart from rare exceptions, there are no elements on the boots that reduce this load, so there are also possible improvements. Among the surveyed drivers, there were no injuries caused in this way, and in the literature [1] there is information that there was a serious injury when landing from a great height, where the driver was on the motorcycle the whole time, with his feet on the footrests.

4.2. Protection Against Pinching

Pinching occurs mainly during falls, when the leg is pressed between two objects. The most common case is when a motorcycle falls on a leg that is on the ground during an accident. The risk of injury increases if the leg is in contact with a sharp edge, such as a stone or a sharper part of the motorcycle.

Protection against pinching can primarily be provided by rigid parts of the boot, more specifically those that do not change shape under the load. The soft parts of the boot, including those that are thicker and designed to cushion impacts, contribute little or nothing to pinch protection. Less rigid parts can somewhat reduce the risk of injury by partially absorbing the impact and distributing the load over a slightly larger area of the leg, thus enabling the leg to bear the load better.

Among the boots tested, all have a very stiff sole and often there is a relatively stiff plastic reinforcement on the forefoot, although not as stiff as the sole. The remaining parts of the boot, including the plastic plates, are not rigid enough to provide significant pinch protection.

The situations in which a boot can provide pinch protection are primarily those where the load is positioned so that it can be borne by the sole. This is, for example, a situation in which the boot (leg) lies sideways on the ground, and the motorcycle falls on it so that it presses against it with a surface that is more or less parallel to the ground, in the area of the sole. The sole can then take the load, prevent the boot from deforming and protect the foot. The sole can protect the ankle and, to some extent, areas further away from the sole, but only if the surface acting on the boot rests on the sole at the same time. If the load acts only on the ankle, or lower leg, the boot will not provide significant protection. In practice, such situations are common, because the ground surface is uneven and the motorcycle has protruding surfaces and edges that can injure the leg. Although there are plastic reinforcements on the boots that make them significantly stiffer than normal footwear, they do not significantly prevent the deformation of the boot in the area of the ankle and lower leg. These are the areas where the strength measurement proved to be meaningless, since the boot can be deformed by hand without much effort. This is also confirmed by the experiences of the surveyed drivers, some of whom have experienced injuries from being pinched. There were not many such injuries, but primarily because there were no stronger pinches in risky places, so the protection provided by the boots was sufficient. On the other hand, the survey recorded a case where pinching caused the fracture of the heel bone. In the literature [2, 3] it is stated that foot, ankle and lower leg injuries are among the more common injuries in competitions. There are no detailed data on the mechanism of injury.

4.3. Protection Against Bending

Bending can occur when the leg is loaded with a force couple. This happens primarily during falls, when an obstacle or ground, a motorcycle and the inertia of the driver's body can act on the leg. Stronger loads can cause bone fractures, and most often the risk is greatest for the ankle joint, which

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can be exposed to excessive dorsiflexion, plantar flexion, inversion, eversion, abduction and adduction, usually causing some kind of a sprain.

Excessive plantar flexion (hyperextension) can occur when the driver falls more or less on his stomach. The knee and toes then rest on the ground, the heel is turned up and can be pressed from above by the falling motorcycle, causing excessive extension of the ankle. A similar load occurs if, during driving, the tip of the boot brushes the ground and the heel remains on the footrest. The ground will pull the toe of the boot back, causing the ankle to bend backwards. To prevent excessive flexion of the ankle, the boot should have sufficient stiffness to support the load. In all models, there is a softer material in front and behind the ankle, which should provide a certain flexibility of the boot to increase comfort. The extent to which this reduces the protection against overextension of the ankle depends on other structural elements and in this respect there are quite large differences between boot models. In a simpler construction, the resistance to bending depends on the material and shape applied on the side surfaces, so some models bend quite easily and others are more rigid, but the question is how much they are able to withstand a greater load. In a more complex construction, on both sides of the ankle there are joints between the plastic panels that cover the foot and lower leg (Figure 1). Those joints allow flexibility and thereby increase comfort, but also reduce protection against bending. That is why some models have a limiter, mostly above the heel, which prevents excessive bending of the ankle (Figure 2).

Another common ankle hazard is excessive inversion or eversion (rolling the foot inward or outward), which could occur when a driver lands their foot on an uneven surface. There were no such injuries among the surveyed drivers, which can be explained by the fact that all boots have a certain lateral bending stiffness, which, as practice shows, is generally sufficient to prevent rolling the foot on an uneven surface. However, there are differences in lateral bending stiffness between boots and these can manifest themselves in other situations where the boot is subjected to a higher lateral bending load.

Some of the surveyed drivers, the vast majority of whom are recreational drivers, had more serious ankle injuries caused by bending. Other research shows that the ankle is among the most vulnerable parts of the body during sports competitions. According to an analysis from an enduro competition [2], of all fractures recorded in competitions, about one third are related to the ankle and foot, although the causes of the injuries are not specified. In the research [4] conducted on motocross races, among the ligament injuries, those on the ankle are not the most frequent, but they have a significant frequency and are the result of some kind of bending.

Preliminary analysis indicates that in terms of resistance to excessive ankle bending there are significant differences between boots, so it would be useful to examine these properties with exact measurements to show the extent to which boots fulfill this protective function.

4.4. Abrasion Protection

Scratch protection is one of the features that are relatively often mentioned in connection with the protective features of motorcycle equipment. It is part of the EN 13634 standard and also the subject of certain papers [5, 6], but primarily in connection with driving on paved roads and clothing for

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motorcyclists, not footwear. Among the surveyed drivers, there were no injuries caused by abrasion, thus it can be concluded that existing boot models provide good protection. This is to be expected, considering the construction of the boots and the fact that during off-road falls there are usually no long slides on rough surfaces (asphalt), which is characteristic of falls on paved roads. In the literature [7] there are data on leg injuries caused by abrasion in enduro competitions, but it is not specified whether they were on the lower part of the legs.

5. CONCLUSION

Preliminary research has shown that the level of protection provided by boots for motorcyclists largely depends on the type of load to which they are exposed, as well as that in terms of certain features there are similarities, and in terms of some other features significant differences between the models of boots. Boots provide the best protection against impacts from small objects and abrasion. When it comes to ankle bending protection, there are big differences between models, from those that provide very little protection to those that provide good protection, which would still be good to check with measurements. In terms of protection against pinching, all boots protect well in certain situations, but in many cases they provide little protection. The research also showed that there are very few scientific articles in this field. Existing studies primarily deal with injury statistics and less with the characteristics of protective equipment. They also rely largely on researches conducted 20 or more years ago. Overall, the research showed that there is room in this area for both improving boots and researching their properties.

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