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Experimental and numerical analysis of seat belt bunching phenomenon

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ABSTRACT

In current cars, loops are commonly used to redirect the webbing which reels out from the retractor to the passenger's shoulder. Some types of pillar loops, also called D-rings, lead to a non-systematic instability. The webbing, which should scroll without hindrance through the D-ring, laterally shifts, bunches and produces the overturning of the ring.

In this paper, this so-called seat belt bunching phenomenon is parsed during a first step with sled test campaigns data. The results of designs of experiments are analysed and discussed.

To expertize this instability issue, an innovative fixture is exploited during a second step to reproduce the phenomenon in a fully controlled manner for dynamic and quasi-static loadings. To assess these sub-system tests, a Digital Images Correlation system is employed to evaluate the strain distribution of seat belt webbing during the bunching phase. Based on these local measurements, a correlation of a Finite Element model of seat belt bunching is achieved using a new shell element for webbing fabric, before proposing an explanation of the phenomenon.

1. Introduction

Automotive manufacturers and suppliers commonly conduct crash tests in order to assess the performance of safety systems on new vehicles. Crash scenarios are reproduced using dynamic tests. For instance, the EuroNCAP protocol; a 64 km/h frontal impact in a 40% offset deformable barrier, is used to simulate a car to car impact. An assessment protocol is then applied to achieve a rating for each body region. The head acceleration, the chest deflection, the femurs loading, compression/extension/flexion of the neck are measured on crash test dummies and a star rating is given. The safest cars obtain a 5-star performance.

During the vehicle deceleration, the dummies are subjected to the collision forces and in the case of a frontal impact, they move forward. To prevent severe contacts between the passenger and the car interior (dashboard, steering wheel), a three-point seat belt restrains the passenger's motion. In parallel, the driver and the passenger airbags reduce the acceleration peak applied to the occupant and distribute the restraint loads on the upper part of the body. To take benefit of their coupled actions, these restraint systems are developed in interaction. Nevertheless, although an airbag has a spectacular action during a collision, the belt, part of the passive restraint system, is the only protection against the ejection of the passenger away from his vehicle.

A safety belt webbing is a fabric material using polyester threads woven on Jacquard weaving looms. The webbing of a width of 48 mm of the belt restraint system has to resist to dynamic loads up to 14 kN. Depending on the type of vehicle, about 3.5 m of webbing is used in the seat belt. The interactions between the warp and weft threads of the fabric control the behaviour of the seat belt during the crash event.

Seat belt systems are usually combined with a load limiter retractor and also pre-tensioner integrated in the retractor, fixed at the buckle or at the lower part of the B pillar (the pillar on which the rear doors are fixed). A D-ring is used on the upper part of this pillar in order to redirect the seat belt, which reels out from the retractor to the passenger shoulder. It is designed to adapt its angular position according to the passenger's motion. Numerous different kinds of D-rings (also called webbing guides) are used in current vehicles: most of them are made of a metal insert on which polymer part in nylon or in acetyl is moulded (see Fig. 1a). In some cases, the ring frame and the guidance surface are made of one piece of metal (see Fig. 1b). In the latest vehicles, the complete webbing guide assemblies are integrated into the trim panel, and only the diagonal belt portion appears (see Fig. 1c).

For some belt geometries (the 3D position of the anchorage points of the seat belt on the vehicle), the use of certain D-rings has led to a non-systematic instability, which is very disadvantageous.

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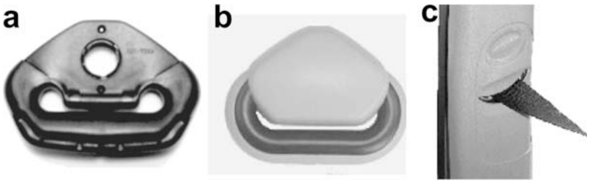

Fig. 1. Webbing guides (courtesy Autoliv).

The webbing, which should scroll without hindrance through the webbing guide, laterally shifts, bunches and produces the overturning of the ring as shown on Fig. 2, where the D-ring has been masked for confidentiality reasons.

This phenomenon is an issue because it might prevent the restraint systems connected to the webbing from working in a normal manner (pre-tensioner, load limiter). In the face of such a problem, various studies [1–4] have been carried out to control this phenomenon and needed to be pursued.

2. Analysis of the phenomenon based on sled tests

To develop restraint systems, numerical simulations are conducted and to confirm the airbag and the seat belt performances, dynamic sled tests are performed.

A sled is a mechanical welded assembly developed to simulate the car interior. The anchorage points of the seat belt are positioned in accordance with the car project specifications. The dashboard geometry is reproduced using foams and seat prototypes are used.

The bunching phenomenon was occasionally observed during these non-destructive sled tests. Previous studies [1] have shown that during this type of test, the plastic deformations of the crash frame are not reproduced and the corresponding absorbed energy is transferred to the webbing (no deformation of the B pillar on which the D-ring is fixed, no deformation of the car floor on which the seat is fixed, no dynamic pitch of the car body). The load applied to the seat belt webbing (measured locally by specific load cells) is thus often higher than the load measured during the corresponding complete vehicle crash tests. Sled tests are known to overload the webbing and to maximize the seat belt bunching likelihood.

To expertize belt behaviours, frontal sled tests campaigns were performed. Based on this experimental approach, designs of experiments have permitted to point out that one of the major factors which influence the phenomenon is seat belt geometry [1]. Several risky seat belt geometries have been then defined but no generic assessment has been developed to explain the seat belt bunching phenomenon.

To pursue the research, a critical analysis of the design of experiments results was proposed. It appears that two consecutive and supposed identical tests may result in two different local behaviours of the ring (bunching for the first one and no bunching for the second one). For instance, sled tests performed with two seats on the same platform (and thus the same pulse, the same dummies, the same belt geometries) gave different results: bunching on one side and no bunching on the other side (see Fig. 3). This status questioned the initial condition of the seat belt webbing and D-ring interactions. An analysis of the initial lateral position of the webbing on the D-ring was then conducted (see Fig. 4, where the D-ring has been masked for confidentiality reasons).

This critical analysis underlined an unexpected factor which influences the bunching likelihood, the initial position of the webbing according to the D-ring slot corners. A tiny variation of the webbing position can modify or delay the bunching phenomenon.

The initial positioning of the webbing on the D-ring was not known at first as being an influential factor on the crash test results because it is usually not a factor under control. Several points can explain this insufficiency:

- The initial position of the webbing on the D-ring is a consequence of the belt geometry. Moreover, the size of the dummy (Hybrid III 05, 50 or 95%ile) and the seat position (slide position, height adjustment position) also vary the webbing/D-ring boundary conditions.
- It is also controlled by component specification, the friction level between the D-ring and the webbing, the friction value between the webbing and the dummy, the spring strength inside the retractor and the webbing slack resulting from the manual buckling of the seat belt on the dummy's body.
- The dynamic ring technology has also an influence on the webbing positioning on the D-ring. In a case of a direct crash test (sled decelerated using deformable bumpers), the initial webbing position is often modified by the tiny sways of the dummy during the acceleration phase. These perturbations can potentially be reduced by the use on an inversed crash sled (sled accelerated using hydraulic valves), but as the seat belt bunching phenomenon is an instability problem, small variations of the sled pulse can also interfere with the webbing behaviour.

The critical analysis of the results of various designs of experiments shows that experimental studies based on sled tests are helpful to investigate the phenomenon but do not lead to a final solution to the instability of D-rings. They enable listing of several important influential factors and show tendencies. Detailed analysis proved that sled dynamics tests are not adapted to the study of the webbing/D-ring interactions, because this test method provokes local dispersions which have an effect on the final result of the experiments.

Numerous sled tests would be necessary to evaluate the trends according to the initial position of the webbing on the D-ring, but the high cost of these sled tests does not enable such methods to be pursued.

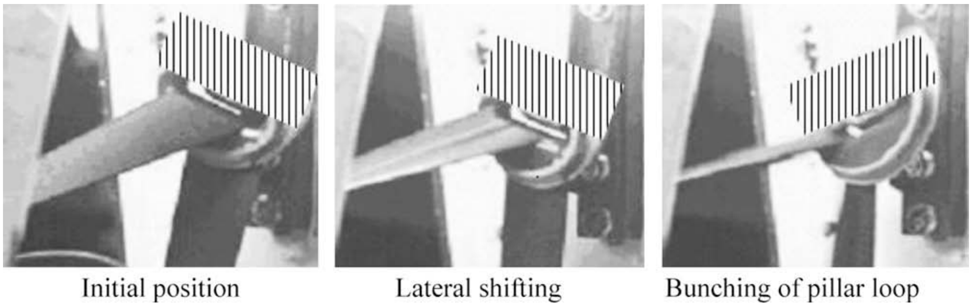

Fig. 2. Seat belt bunching phenomenon.