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FINITE ELEMENT ANALYSIS OF A SEAT BELT BUCKLE DEVICE

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ABSTRACT: In the last years, there has been rapid and extensive progress in automotive technologies. These technical advances include devices that provide increased protection for the occupants of the vehicle in case of crash and systems that allow drivers to avoid collisions, or at least to mitigate their severity. Integrated systems for restraining the occupant, used in automotive applications, have shown to improve the safety of the occupant and to decrease the risk of injury during impacts of motor vehicles. Although safety belts and air bags are always been considered among the primary safety devices, today the seat belt system is widely regarded as being the most important element of safety equipment in a vehicle. In the first section of this paper, the most important elements of the safety equipment in a vehicle are described. The second section presents the modeling, analysis and evaluation techniques for the Seat Belt Buckle Assembly strength, used in order to ensure the safety of the occupants in conditions of impact. Proper design of the seat belt buckle assembly is crucial, as in case the seat belt buckle assembly can not endure the load that was derived by the motion of an occupant during an impact, the seat belt system can not play the role of a restraining system anymore. In order to perform this analysis and evaluate the strength, we examine the effectiveness of a latch plate as component of the seat belt buckle assembly, using the finite element analysis method.

KEYWORDS: safety device, safety belt system, seat belt buckle assembly, finite element analysis

❖ INTRODUCTION

Vehicle crashworthiness and occupant safety remain among the most important and challenging design considerations in the automotive industry. In the recent years, there has been rapid and extensive progress in automotive technologies, especially with respect to electronic sensing and control systems, which allowed engineers to develop a wide range of "high-tech" safety systems. These include devices that provide increased crash protection for vehicle occupants, and systems that may allow drivers to avoid collisions or, at least, to mitigate their severity. Some of these systems, described in Fig.1, are available as standard equipment on new vehicles, while others involve additional costs, as part of specific and optional equipment packages on certain vehicle models.

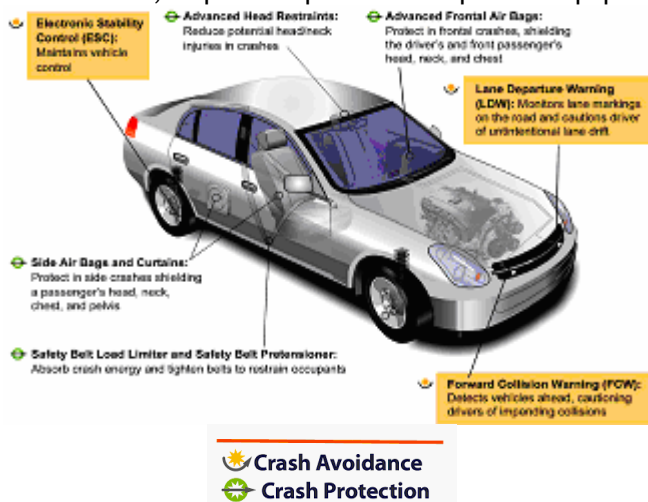


Fig.1 Safety technologies:
Crash Avoidance and Crash Protection



Fig.2 Safety belts and air bags

The most important safety devices are considered today the Safety belts and Air bags (Fig.2) which save thousands of lives each year (for example, according to the reports [5], the use of seat belts in 2009 saved an estimated of 12,713 lives). The air bag is a proven and effective safety device, but it doesn't replace a seat belt. Air bags are designed to work only with seat belts, because if an

occupant doesn't wear his seat belt, he could be thrown into a rapidly opening frontal air bag and a movement of such force could injure or kill him. Consequently, the seat belt system is widely regarded today as being the most important element of safety equipment in a vehicle. When used according to [1], seat belts are approximately 45% effective at preventing fatal injuries and 67% effective at preventing serious injuries. Moreover, nearly all safety experts agree that buckling up dramatically increases the chances of surviving an accident, and those seat belts reduce the risk of death for a front seat car occupant by about 50 percent.

Despite this safety record, the performance of the belt systems is continuously being refined. Recent papers discuss the development of 4-point harnesses for use in production vehicles [2], [3], while devices such as pretensioners and belt load limiters [4] are becoming common features in contemporary vehicles.

The development and the evaluation of protection measures against the effects of accidents, require an accurate assessment of the operational behavior in the exploitation of safety systems, and involve a good knowledge of the tolerance of the human body, as well as its mechanical response to impact.

❖ STANDARD THREE-POINT SAFETY BELT SYSTEM

The safety belt, also called seat belt, is part of an overall occupant restraint system. This is intended to reduce injuries by stopping the wearer from hitting hard interior elements of the vehicle or other passengers, respectively the so-called second impact [6], and by preventing the passenger from being thrown-out from the vehicle. A properly secured seat belt offers protection in head-on, side and rollover collisions, by securing in the life space of the vehicle. In fact, the belts system help spread out the energy of the moving body in a collision over the chest, pelvis, and shoulders.



Fig.3. Standard three-point seat belt system and its components

The standard three-point belts shown in Fig. 3a, attaches to the car in three places, two mount near the rear of the seat bottom and one towards the top of the side pillar, offering a maximum of comfort and convenience. The seat-belt latch plate clips into a buckle Fig.3b, which in the front seats of cars is usually placed at the end of a stiff stalk. A pretensioner Fig.3c, and a retractor device Fig.3d, are included as part of the safety belt system. In the event of an impact, the safety belt system is designed to grip the belt and not allow the occupant to travel forward any more than they already are.

The seat belt buckle assembly, Fig.3b, must be able to withstand extremely high loads during a crash, and at the same time it must be easy to open even when heavily loaded. Moreover, the buckle assembly must withstand high accelerations in all direction without opening. This feature is critical when the seatbelt system includes a pretensioner, as such a pyrotechnic device pulls rapidly the buckle in one direction towards the floor and then the pulling force suddenly switches in the other direction. (Fig.4)

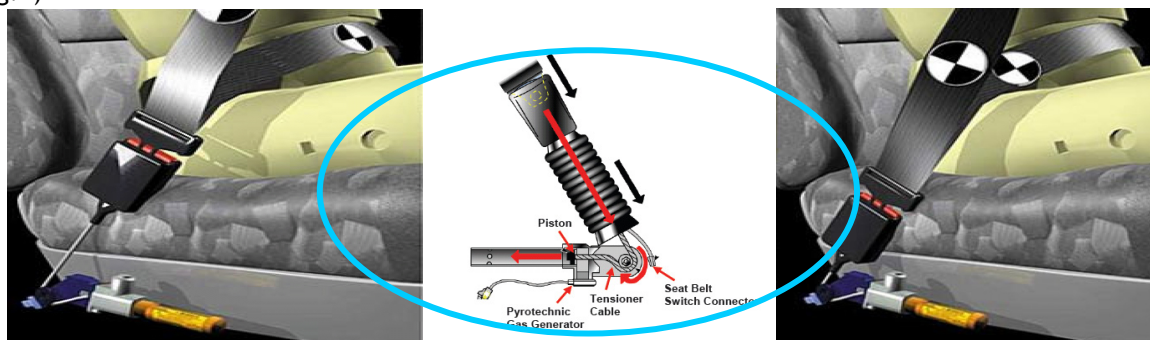


Fig.4 Functions and operating mode of a pyrotechnic pretensioner

❖ FAULTY SEAT BELTS

If the seat belt buckle can not endure the load that was derived by the motion of an occupant during a frontal impact, the seat belt can not do the role of a restraint system any more. Thus, proper strength of a seat belt buckle is essential in the case of a frontal impact.

In general, motor vehicle safety teams check the performance of their equipment to protect the occupant against unreasonable risk of accidents and of death or injury in an accident. In this context, a safety defect is defined as a problem that exists in a motor vehicle or in its equipments and that: poses a risk to motor vehicle safety; may exist in a group of vehicles of the same design or manufacture, or in items of equipment of the same type and manufacture.

Examples of defects considered safety-related to a vehicle occupant, are listed below:

- ❖ Critical vehicle components that break, fall apart, or separate from the vehicle, causing potential loss of vehicle control or injury to persons inside or outside the vehicle.
- ❖ Seats and/or seat backs that fail unexpectedly during normal use.
- ❖ Safety seats that contain defective safety belts, buckles, or components that create a risk of injury, not only in a vehicle crash but also in non-operational safety of a motor vehicle.
- ❖ Air bags that deploy under conditions for which they are not intended to deploy.

A typical auto crash is viewed as having “two collisions”: the “first collision” occurs when the vehicle impacts another vehicle or a fixed object; the “second collision” (following immediately, often after only milliseconds, the first collision) occurs when a vehicle occupant impacts the interior of the vehicle or is ejected and hits the ground (the literature notes also the existence of a “third impact”, between the internal organs and the frame of the body).

The purpose of a seat belt is to either prevent the second collision or to minimize its injury-producing potential. When it works properly, the seat belt is indisputably the most important safety device in an automobile, however when it works poorly or completely fails to work, the seat belt can cause serious injury and even death.

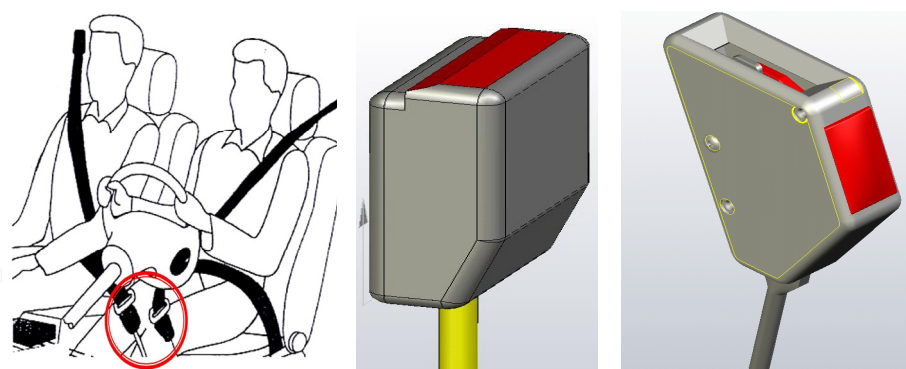
Seat belts can fail to restrain occupants due to both poor design and/or faulty manufacturing. Some of the more common defects include: Inertial unlatching & False latching, or/and the Failure of some component parts of the seat belt buckle. Consequently, the ways to unlatch a seat belt buckle in an accident, [7], can be: Overload; Inadvertent contact; False latch/Partial engagement; Inertial release. During a collision in such situations, the seat belt becomes unlatched and can allow the latch plate to pull out of the buckle. As a result, the occupant is essentially unbelted and unrestrained and, frequently, can be ejected from the car. If a seat belt system failure is suspected, the evidence that a seat belt failed because of design or manufacturing defects is often subtle and can be difficult to detect; since it is extremely difficult to prove that a seat belt failed without the physical evidence, it is important to preserve the failed seat belt system and to attach it to the technical expertise.

❖ PRESENTATION OF THE STUDIED DEVICE

A safety belt buckle device, Fig.5a, is designed to coupling the seat belt that fixes to seat the occupant of the vehicle in order to limit its movement during a shock, and thus, during a strong deceleration, the occupant of a vehicle in motion is not projected in the moving direction as result of the accumulated kinetic energy.

Generally, the energy current safety belts are equipped with buckles devices similar to those presented in Fig.5b and Fig.5c.

The 3D model of the studied coupling device (with side-release button) is shown in Fig.6.



a. Studied area b. End-release buckle c. Side-release buckle
Fig. 5. Studied area and Types of safety belt buckle devices

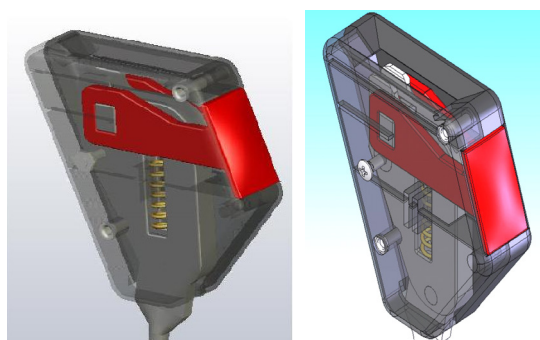
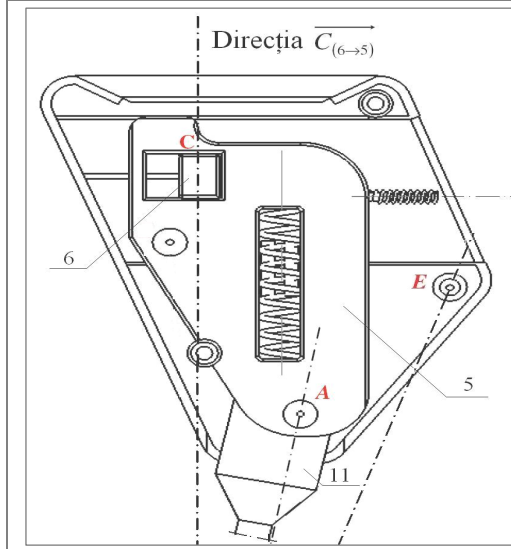
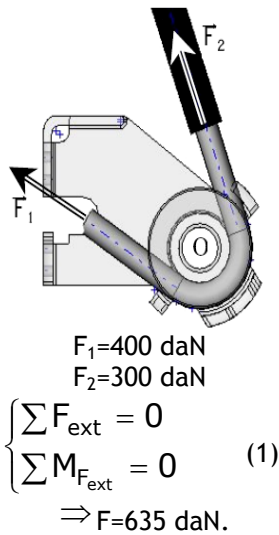


Fig.6. 3-D model of the studied coupling device

❖ EFFORT EVALUATION IN PRETENSIONED SEAT BELT SYSTEM

The static analysis of the cable-guide subassembly, Fig. 7a, followed by the solving of the equations equilibrium system (1), with $F_1=400$ daN and $F_2=300$ daN, give as result the forces in the belt system, $F=635$ daN. After the decomposition of this

force, at A, C and E points, Fig.7b, we obtained the following values of forces:



$\bar{A}_{1 \rightarrow 5} = 635 \text{ daN ;}$
 $\bar{C}_{6 \rightarrow 10} = 343 \text{ daN ;}$
 $\bar{E}_{1,2 \rightarrow 5} = 350 \text{ daN.}$

Fig.7. Evaluation of the resultant force in the safety belt system and its components

❖ FINITE ELEMENT ANALYSIS OF THE BUCKLE LATCH PLATE

The belt buckle assembly must have the capacity to transmit the forces being put on the system. In case one of its component parts, in particular the latch plate, can not endure the load that was derived by the motion of an occupant during an impact, the safety belt system can not play the role of a restraining system anymore.

Therefore, the latch plates of the seat belts, although have different designs being manufactured by different companies, are an important element of the system. The importance of this element lies in its own security and is related to assure the functional role of the safety belts systems.

- MATERIAL PROPRIETIES: the analyzed latch plate is made of steel grade CK55 (corresponding to OLC 55 X, STAS 880), whose properties are listed in Table 1a and 1b.

Table 1a. Mechanical properties in the quenched and tempered condition (+QT)

Mechanical properties	Mechanical properties for the ruling sections (see prEN10083-1:2002, Annex A) with a diameter (d) or for flat products thickness (t) of		
	$d \leq 16\text{mm}$ $t \leq 8\text{mm}$	$16\text{mm} < d \leq 40\text{mm}$ $8\text{mm} < t \leq 20\text{mm}$	$40\text{mm} < d \leq 100\text{mm}$ $20\text{mm} < t \leq 60\text{mm}$
Re min. (MPa)	550	490	420
Rm (MPa)	800-950	750-900	700-850
A min. (%)	12	14	15
Z min. (%)	30	35	40
KV min. (J)	-	-	-

Table 1b. Mechanical properties in the normalized condition - (+N)

	Mechanical properties for products with a diameter (d) or, for flat products thickness (t) of		
	$d \leq 16\text{mm}$ $t \leq 16\text{mm}$	$16\text{mm} < d \leq 100\text{mm}$ $16\text{mm} < t \leq 100\text{mm}$	$100\text{mm} < d \leq 250\text{mm}$ $100\text{mm} < t \leq 250\text{mm}$
Re min. (MPa)	370	330	300
Rm min. (MPa)	680	640	620
A min. (%)	11	12	12

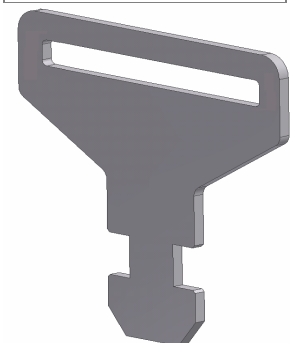
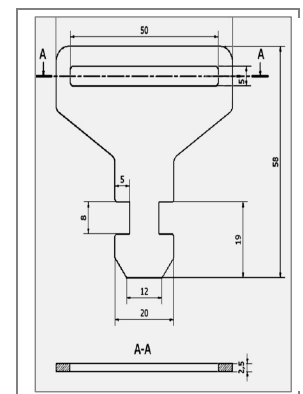


Fig.8. Geometric parameters and the 3-D model of the latch plate

- GEOMETRIC PARAMETER AND 3-D CAD MODEL: the geometry of the latch plate, shown in Fig.8, was based on these functional requirements and is in accordance with the configuration of the belt buckle.

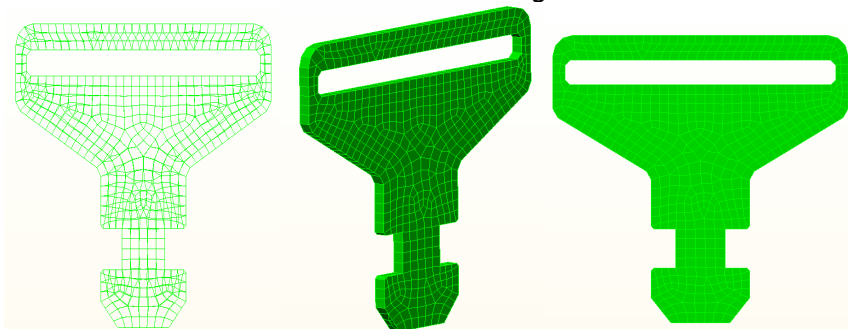


Fig.9. Discretization (meshing) of the latch plate model

- FINITE ELEMENT ANALYSIS OF THE LATCH PLATE

The finite element analysis performed using Algor software, involved the following steps:

- ❖ Conception of the 3-D CAD model of the latch plate (or transfer to Algor a CAD model designed in another modeling tools/dedicated software/, like Inventor, Mechanical Desktop, SolidEdge, in .stp format file), for creating the 3D geometry of the part/assembly to perform FEA.
- ❖ Save of the 3D CAD geometry in neutral format like IGES, STEP etc. Though some of the FEA packages allow importing the CAD geometry directly from some of the 3D CAD packages.
- ❖ Start of FEA package and import the CAD geometry into the FEA package.
- ❖ Defining Material Properties: modulus of elasticity, Poisson ratio, etc.
- ❖ Defining the displacement boundary conditions (Fig.10) and applying the mechanical loads (Fig.11);
- ❖ Discretization (meshing) of the model (Fig.9);
- ❖ Performing of the finite element analysis, respectively obtaining the solution of the finite element matrix equations (solved for the unknown displacements, given material properties, forces, boundary conditions and mesh size);
- ❖ Analysis and interpretation of the FEA results (Fig.12), and conclusions drawn from the analysis.

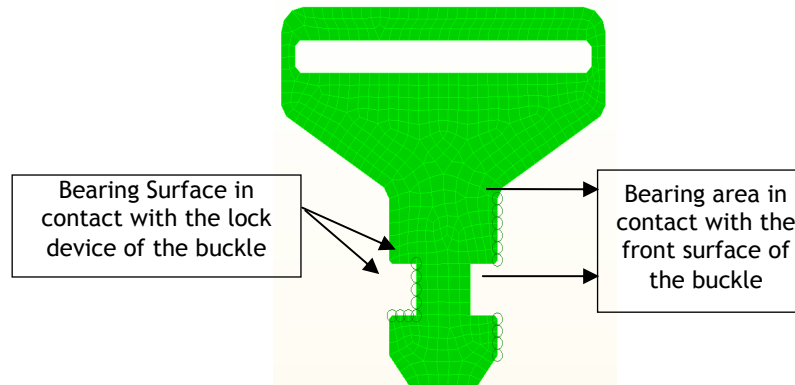


Fig.10. Boundary displacement constraint conditions

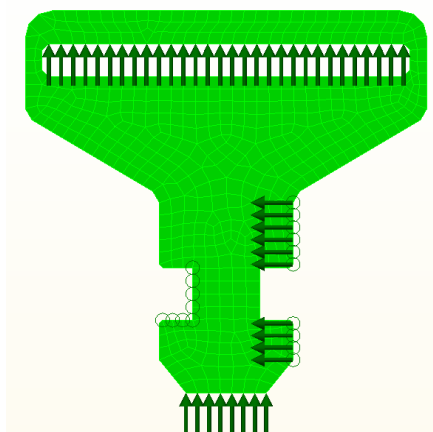


Fig.11. Applied of mechanical loads

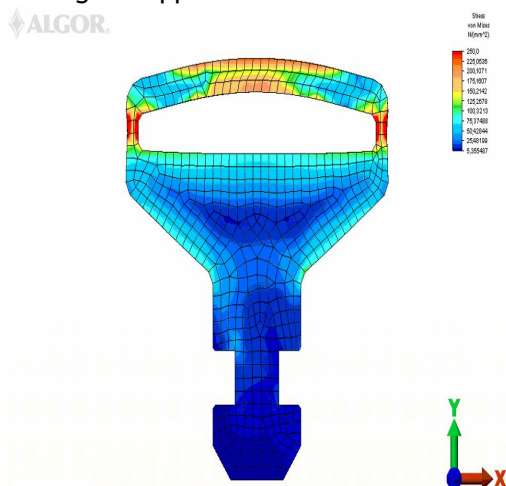


Fig.12. Finite Element Analysis of the safety belt latch plate. Distribution and values of Stress

❖ INTERPRETATION AND CONCLUSIONS. FUTURES STUDIES

The CAD modeling and the Finite Element Analysis of the seat belt system (buckle assembly and latch plate), was carried out in order to verify the safety of the car occupants in impact conditions. The proper design of a seat belt buckle is essential for the situation of a frontal impact, because if the buckle assembly can not endure the load derived by an occupant motion during a frontal collision, the safety belt can not serve as functional restraint system.

The effectiveness of the component parts of the safety belt assembly was analyzed using the *Algor V Release* software, based on the Finite Element Method, and the results that we obtained reveal the correct design conception of the examined elements.

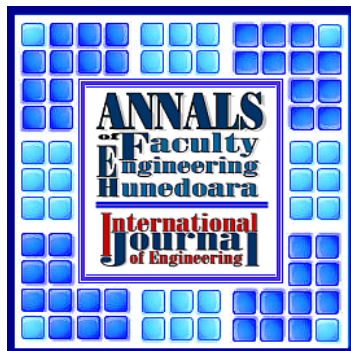
In our future studies, we are planning to do further development on the subject of analyzing the passive safety systems using FEA software. This work is motivated by the continuously increasing standards for protection measures against the effects of accidents.

These require an accurate assessment of the operational behavior of the safety systems in exploitation, and involve a good knowledge of the tolerance of the human body, as well as its mechanical response to impact.

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