UNIVERSIDADE DE ÉVORA

ESCOLA DE CIÊNCIAS E TECNOLOGIA

DEPARTAMENTO DE FÍSICA

Investigation, optimization and re- design of a body car part, especially in terms of weight and cost reduction, material substitution, structural rigidity and fixation system.

Tiago Miguel Grilo Mayer de Oliveira

Orientação: Prof. Eng. José Eugénio Garção

Diplom. Eng. Hilmar Schulze

Mestrado em Engenharia Mecatónica

Dissertação

Évora, 2013

Universidade de Évora

Mestrado em Engenharia Mecatrónica
MSc Dissertation

Investigation, optimization and re- design of a body car part, especially in terms of weight and cost reduction, material substitution, structural rigidity and fixation system.

Author:
Tiago Miguel Grilo Mayer de Oliveira

Coordinator Universidade de Évora:
Prof. Eng. José Eugénio Garção

Co-Coordinator Volkswagen AG:
Diplom. Eng. Hilmar Schulze

Inspiration

“My interest is in the future because I am going to spend the rest of my life there.”

Charles Kettering

“First say to yourself what you would be, and then do what you have to do.”

Epictetus

“Wherever you go, go with all your heart.”

Confucius

“Opportunity is missed by most people because it is dressed in overalls and looks like work.”

Thomas Edison

“A person, who never made a mistake, never tried anything new.”

Albert Einstein

“Be the change you want to see in the world”

Mahatma Gandhi

The research reported in this thesis is supported by Universidade de Évora, Portugal.

The research reported in this thesis is part of the product improvement process of Volkswagen Entwicklung Aufbau.

Universidade de Évora advisor:

Prof. Eugénio Garção

Volkswagen AG Co-advisor:

Diplom. Eng. Hilmar Schulze

Abstract

Reducing vehicle mass in order to improve fuel efficiency is one of the biggest challenges of actually automotive society. This objective could be achieved using lighter materials or less pollutant engines, nevertheless these technologies are currently expensive and engineers must develop high efficient safety vehicles that could be economically competitive in their class. The immediate objective of this research is to analyze a body car part in order to improve its weight characteristics without compromising the main function of the component as well as the final price per unit. Different alternatives were taken into study, selecting the lightweight design as the best practice to implement in this case, reducing substantially the weight of the part, keeping strength resistance and lowest price as possible.

Investigação, Otimização e Redesenho de uma Peça Automóvel, especialmente em termos de redução de massa e custos, substituição de material, rigidez estrutural e sistema de fixação.

Resumo

Reduzir a massa total de um veículo de modo a melhorar a sua eficiência energética é um dos maiores desafios dos grandes construtores automóveis. Este objetivo pode ser atingido através da utilização de materiais mais leves ou motores menos poluentes, contudo estas tecnologias ainda são demasiado dispendiosas, sendo que os engenheiros responsáveis pelo desenvolvimento de um novo modelo, devem fazê-lo tendo como sempre premissa um veículo extremamente eficaz em termos de segurança, sendo economicamente competitivo na sua classe. Este estudo tendo como objetivo analisar um componente utilizado na construção da carroçaria de um veículo atualmente no mercado, de modo a otimizar a sua massa, não comprometendo a sua função principal assim como o preço final por peça. Diversas alternativas foram tidas em conta, tendo sido optado como caso mais favorável a otimização de design, reduzindo substancialmente a massa do componente, mantendo a sua resistência e o mínimo investimento possível.

Acknowledgements

I would like to thank my company supervisor, Dipl. Eng. Hilmar Schulze, for the great opportunity of being project integrated in the biggest European car manufacturing Group, Volkswagen AG, in order to proceed with this project. I would like also to thank to my University de Évora supervisor, Prof. Eugénio Garção, for all the support and good practices from Portugal during the most critical stages of this study.

Special thanks to all my family and closest friends, for all the strength and courage given during the last months.

Table of Contents

List of Figures

List of Tables

Nomenclature

Roman lowercase

symbol	*description*	*unit*
n	Strain hardening coefficient	-
e	Elongation	mm
p	Surface pressure	Pa

Roman uppercase

symbol	*description*	*unit*
P	Performing force	N
T	Thickness of part material	mm
S	Shear strength	N/m^2
E	Young modulus	-

Greek

symbol	*description*	*unit*
τ	Friction force	N
ε	Membrane strain	mm

Mathematical notation

symbol	*description*	*unit*
R_m	Tensile strength	MPa
$R_{p0.2}$	0.2% proof strength	MPa
σ_y	Yield stress	MPa
$A_{\%}$	Elongation to failure	%
r_α	Lankford ratio	-

Acronyms

VW	Volkswagen
UE	Universidade de Évora
EK	Entwicklung Aufbau
ECE	Economic Commission for Europe
TSI	Twincharged Stratified Injection
TDI	Turbocharged Diesel Injection
hp	Horsepower
DIN	Deutsches Institut für Normung
HSLA	High-strength low-alloy steel
JIS	Japanese Industrial Standards
AFNOR	Association Française de Normalisation
3D	3 Dimensional

1

Introduction

Abstract: In this chapter, an introduction of Volkswagen Group is given, accompanied by an overview of the current improvement process used by Volkswagen in order to reduce mass and cost for vehicles already in production, which was used as aim for this research.

1.1 - Project Environment

One of biggest concerns in the actually society is the increasing of Global Pollution and all the problem advent from this factor. Automotive industry is one of the biggest contributors for this problem and despite the auto manufacture itself; automobile exhausts emit several components that have adverse health impact among the exposed population.

Rapid increase in the number of vehicles is another reason for increasing automobile pollution and in order to counter this tendency, automotive manufacturers and their suppliers must innovate in all areas of vehicle design in order to maximize fuel efficiency and reduce emissions.

In order to achieve this goal, automotive manufactures can adopt several strategies, starting on more efficient engines, redesigned better aerodynamic autos, eco-

This chapter is largely based on internal Volkswagen AG information, including Volkswagen Official Website and product improvement process.

friendly tires or the latest tendency, new lightweight materials and their integration into vehicle designs.

Reducing vehicle mass by using lighter materials is one of the means to improve fuel efficiency, a feature society as a whole is pushing aggressively toward. In order to address the potential safety concerns associated with lightweight materials, new technologies and tools are being innovated, and can be used in the design of vehicles to achieve both the energy and safety goals. Advanced modeling and simulation using high performance computers will be necessary to quickly develop entirely new materials, while ensuring vehicle performance, safety, and efficiency. The lightweight, energy-efficient vehicles of the future will be manufactured out of materials that do not even exist today: materials that will be lighter, stronger, safer, and more environmentally friendly than current materials. The application of new lightweight materials goes well beyond ground vehicles, as well. Aviation, commercial transport, shipping, and many other sectors can benefit from lightweight materials.

Although lightweight materials are more expensive than the current steal used in automobile manufacture and this is the real challenge that engineers have to overtake in order to develop high efficient safety vehicles that could be economically competitive in its class.

1.2 - The Volkswagen Group

The Volkswagen Group has its headquarters in Wolfsburg and it is actually one of the world’s leading automobile manufacturers and the largest vehicle maker in Europe.

In 2012, the Group increased the number of sold vehicles from 8.265 million in 2011 to 9.3 million.

In Western Europe, Volkswagen Group represents 23% of new vehicles market, which revenue in 2011 totaled 192.7 billion euros regarding sales. Profit after tax in the 2012 financial year amounted to €21.9 billion, €6.1 billion more as in 2011.

Currently the Volkswagen Group is composed by 12 brands from seven different European countries: Volkswagen Passenger Cars, Audi, Porsche, Volkswagen Commercial Vehicles and MAN from Germany, SEAT from Spain, Bentley from United Kingdom, Bugatti from France, SKODA from Czech Republic, Lamborghini and Ducati from Italy and Scania from Sweden.

Each brand has its own character and operates as an independent entity on the market. The product spectrum extends from low-consumption small vehicles (Volkswagen up!, SEAT Mii or SKODA Citigo) to luxury class (Audi A8) or super sport automobiles (Bugatti Veyron or Lamborghini Aventador) and more recently to motorbikes with Ducati. In the commercial vehicle sector, the product offering ranges from pick-ups (Volkswagen Amarok) to buses and heavy trucks with MAN, Scania or especially in South American market with Volkswagen Trucks.

The Volkswagen Group is also active in other fields of business, manufacturing large-bore diesel engines for marine and stationary applications (turnkey power plants), turbochargers, turbomachinery (steam and gas turbines), compressors and chemical reactors, and also producing vehicle transmissions, special gear units for wind turbines, slide bearings and couplings as well as testing systems for the mobility sector.

As curiosity, Volkswagen Group is also active in food service industry with Volkswagen ServiceFactory, not only to serve meals to its employees in each plant but also the sell to general public. Taking an example “Volkswagen Currywurst” or “Volkswagen Ketchup” are already cult item in some cities around Germany.

According to 2012 data, Group had 100 production plants in 18 European countries and a further nine countries in the Americas, Asia and Africa, employing

550.000 workers worldwide, producing 34,500 vehicles or involved in vehicle-related services in 153 different countries.

As Volkswagen Group's goal to offer attractive, safe and environmentally friendly vehicles which are competitive on nowadays market and which set world standards in their respective classes.

This development has made Volkswagen AG not only one of the world's largest company within the automobiles production sector with 9.3 Million vehicles sold in 2012, but also a true global player.

1.3 - Product Improvement Process

This project started integrated in the Volkswagen's product improvement process for series vehicles. This program has as main goal the reducing the mass and/or costs regarding product in a current series production vehicle, each means search for some new strategies, new ideas or new standards in order to reduce the total mass and/or costs of a singular part and consequently improve the vehicle.

1.3.1 – Strategy and premises

A product improvement process is started based on an improvement idea to a specific vehicle or platform, each means that, this kind of program could be used not only in a specific part for a specific model vehicle, but also integrated in a whole class or segment involving several different models in different plants around the world – platform components.

At a first analyze it is easier to implement an improvement in one part for one single vehicle, where is necessary to involve one supplier, a single plant that produces the vehicle and also in case of special parts that request crash-test or other special tests, it would be simpler and faster to proceed.

However, in several cases in order to improve significantly one part it is requested a higher investment, which could not be feasible considering the production volume of one single model. Regarding this issue and also taking in mind all the bureaucratic process behind, often it is better to improve a part that is common to several models, where the considered the total volume is higher and easier to amortize the investment.

Independently on how complex is a specific product improvement process, there is always a multidisciplinary team behind each project. This means that each idea have a team constituted by people from different departments in order to analyze the consequences of each change. Taking an example, in order to improve the geometry of a single metal part, it is necessary at first time the responsible engineer, who makes the improved design, after the buyer/ purchasing department contacts the supplier in order to see each are the impacts of this ne geometry to his current production process (new tools, new process flow, new logistic processes) and also all the requested investment in order to have the new part. At the same time the affected plants are also contacted in order to check if the new part will need new assembly and logistic processes with the necessary investment associated. Finishing the consulting step, the product improvement process coordinator for each area together with financial department will check the feasibility of the project. In this case for all the product improvement processes, they should be profitable after maximum of 12 months, i.e. all the investment must be paid after 1 year of introduction, including already the mass or cost improvement.

When a project is feasible would be presented to the Volkswagen board and implemented in the vehicles.

Starting to do a deeply analyze of the product improvement process, in is important to understand step by step what is really done. The program is divided in 6 main stages, as presented on Figure 1.

Figure 1: Flowchart from a product improvement process. (*Volkswagen product improvement process flowchart*)

Each step is based in different premises and also, as referred before, made by different departments.

Starting with stage 1 "Idea generation", different ideas could come from different ways. A single worker could raise it or most commonly, Volkswagen has its own ways in order to find improvements possibilities.

First method is based on meetings, where are discussed specific parts that were already identified as items with improvement potential. In these meetings, those parts are compared to similar parts or concepts, not only inside the Volkswagen Group but also to concurrent vehicles. In the second case, Volkswagen's part are analyzed against to other brands, knowing the price from a concurrent part, it is proposed to do the necessary actions in order to develop a better and cheaper one.

Another very effective method consists in several meetings including different departments, where vehicles from other automobile groups are analyzed in order to find good practices already implemented and better concepts with more improvement capacity that could be used by Volkwagen's vehicles.

Third Method is the electronic analyze, where suppliers from electronic components, those usually are common not only between brands inside the same automobile group but also between different group, as example Bosch, which supplies not only all brands in Volkswagen Group but also BMW Group and Mercedes, analyze the parts that they supply, which could be Hardware or Software, comparing and trying to improve them.

At the same time is also possible to have the same process with another type of suppliers. In this case the collaborators from Volkswagen together with the supplier try to improve some parts or processes inside the supplier plants.

Continuing with the same philosophy, there is another used concept; where different suppliers are nominated and together with Volkswagen departments try to find improvements in their supplied components or processes. This kind of method is more used when the same part is delivered from 2 or more different suppliers and it is necessary a mutual agreement between all companies.

Similar to the previous methods, there is another concept where the plant that uses a specific part is nominated in order to participate and help in the improving process. In this case not only the part is analyzed but also all the assembly process, in order to be improved, reducing the total costs of the vehicle.

The last existent used method consists in the nomination of a multidisciplinary team in order to make a Benchmark not only between brands and concepts but also between regions.

Different regions have different specifications and could occur that a specific improvement in Europe can have negative impacts on plants or sales in other continents. This type of Benchmark is more often used in costumer relevant changes, where specific markets are analyzed in a costumer point of view.

The second step from a product improvement process is called Idea’s potential. Where engineers and buyers must analyze if the improvement ideas are technical feasible and are according to safety regulations. Regarding buyers, it is also required to have all the costs from the supplier, especially when are materials or processes modifications.

After analyze, the results are shown in multifunctional team meetings to be discussed. At this stage all the documentation regarding idea sheet, costs sheet and basic presentations are starting to be prepared.

The third stage is where necessary actions are discussed. In this step all the improvements have already associated costs and technical feasibility and they are presented to the responsible from all markets and/or plants where it is planned to introduce the component, in order to have a direct approval. In case of design or costumer relevant parts, the proposals must be sent to the marketing and design departments in order to be accepted.

After the presentation of each improvement in a product improvement process pre-meeting the official alteration sheet is started and the product team from the affected model is informed in order to decide on each model's update could be implemented the changed part.

Continuing with the regular process, all the improvements are presented to Volkswagen board. This process is the fourth stage from a product improvement process program which is called Actions Decision.

At this stage improvements can be presented in 2 different ways: costumer or design relevant are presented as a prototype part already assembled in the vehicle, in order to have a better overview of what consist exactly the alteration; or in the improvement sheet when the part is not costumer or design relevant.

After an official approval by the board, the improvement is confirmed in Volkswagen's systems and, as referred before, product team must define on each model's upgrade will be implemented, which could occur twice per civil year.

The last 2 steps are Actions Implementations and Financial Confirmation, where improved parts are implemented in production as well as all the financial improvement as cost or mass reduction per part is confirmed.

1.4 - Safety in Automobile Vehicles

Taking a brief analyze from automobile safety, Volvo was the first vehicle manufacturer to offer a nowadays known front-seat three-point seat belt as standard equipment in Volvo Amazon in 1959. This kind of technology has as main function a better restrain of the occupant during an impact to prevent his ejection, comparing to a two-point seat belt equipment.

This system is shown on Figure 2 and proved to be a great improvement in automobile security and nowadays it is requested by law for whole vehicle’s seats.

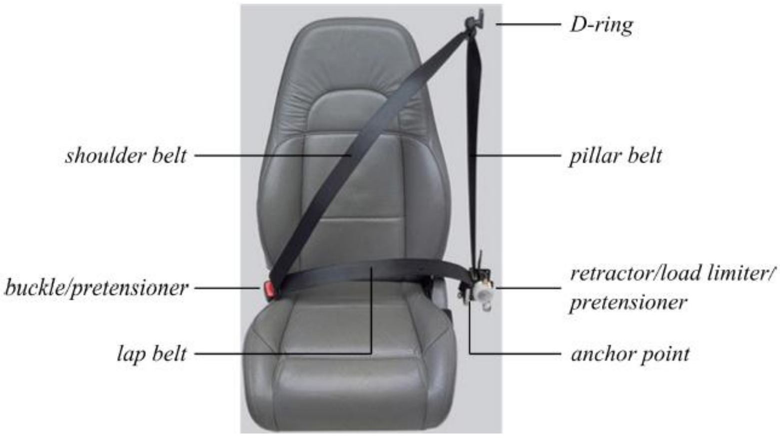

Figure 2: Three-point seat belt system. (*Delphi, Inc.*)

2

The Project

Abstract: In this chapter, an introduction from the project is given, taking special attention on the basic premises necessary to its development. Other aspects as constraining for an improved design and benchmark through different concurrent vehicles with similar concepts will be also approached.

2.1 - Introduction

In this Project it is proposed to investigate one body vehicle part in order to improve it reducing substantially its mass not compromising its basic functions. This body vehicle component is a seat belt guide rail from the second seat's row middle seat present in 2010 Volkswagen Sharan. It is proposed to investigate new technologies, new materials and also new geometries to achieve the maxim improvement in terms of mass taking always into account the final price and the necessary investment of the part in order to use it in current production.

As referred before, the vehicle in study is the second-generation from Volkswagen B-class MPV, which was launched at the 2010 Geneva Motor Show and a month later the second-generation of its sibling model, the SEAT Alhambra, was officially announced.

This chapter is largely based on internal Volkswagen AG information, including Volkswagen Forschung und Entwinklung and Volkswagen Wettberwerbanalyse.

Although still built at the Volkswagen Autoeuropa plant in Portugal, the new model inherits only its name from the previous Sharan, compared to which it is 220 mm longer, 92 mm wider and 12 mm lower, with the wheelbase lengthened by 75 mm.

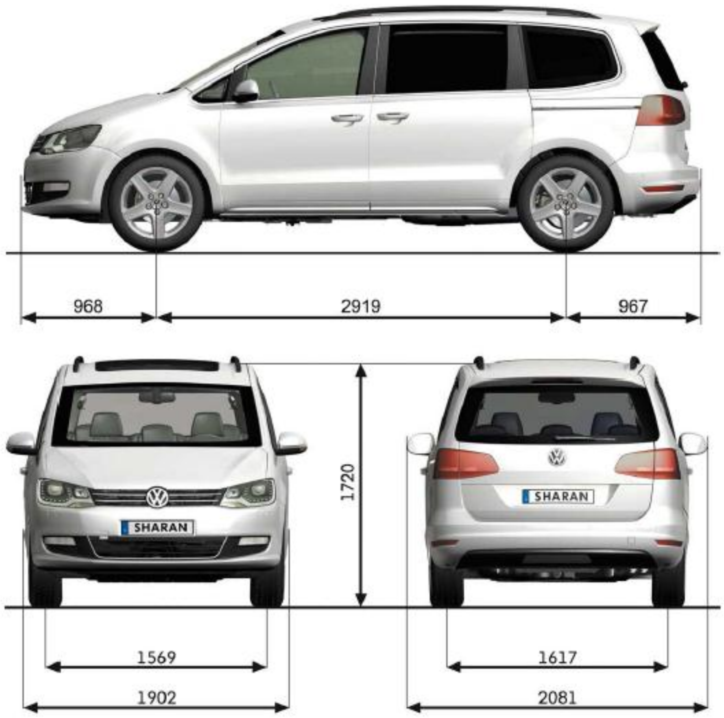

Figure 3: 2010 Volkswagen Sharan dimensions. (*Volkswagen AG*)

Mass has been reduced by 30 kg, having now 1723kg (considering the engine 1.4TSI, 148 hp). The initial engine range comprises 1.4-litre TSI (148 hp) and 2.0-litre (197 hp) petrol options, plus two 2.0-litre TDI diesel engines, rated at 138 and 168 hp. The rear doors now slide open rather than being hinged.

This vehicle is 7 seats MPV placed in the B-Segment analog to Ford Galaxy, Mazda 5, Renault Espace and Citröen C8. According to the latest market studies, this vehicle segment is one of the first options to big families with 2 / 3 children or to mid / big size companies not only to use in day by day but especially for big travels, mainly due to the characteristics of this type of vehicles: very comfortable and with the same technological solutions as a normal / premium midsize vehicle with more free interior space, better design as minivan and functional not only to transport passengers but also carry goods.

In this segment, the compromise between interior passenger's safety, free space and comfort and also fuel economy is very important to the final costumer. Taking this aspect as main premise, manufactures work hard in order to offer the most safer vehicle with the biggest interior free space and comfort that can run the more kilometers with less petrol as possible. This is actually the biggest challenge to automotive engineers: relation comfort / fuel economy.

The relation comfort vs. economy takes even a more important step when the final price is the most important factor for approximately 90% of the costumers. It is possible to develop a super lightweight vehicles using materials specially made for motorsport or aeronautic proposals, including all the top technology and maximal fuel economy, however its final price would be something not achievable to an ordinary costumer that search for this type of vehicles. Due to this fact, nowadays the strategy is offer to public a vehicle with high technology equipment in terms of comfort and safety, more advanced fuel economy engines and with an improved lightweight design using not only lightweight material but mostly using most advanced engineering design parts. With this last aspect it is possible to produce and sell a lightweight vehicle with a reasonable price that costumers can afford.

Following this philosophy and taking part on the Volkswagen Group's product improvement process program (described on 1.3 *Product Improvement Process*), this project will have its focus on one particular Body part in order to improve it and having always in minded the cheapest price and the lowest investment as possible.

The part itself, as already referred, is a seat belt guide rail used as the second row middle seat belt fixing point from the restraint system. This component is made by HC340LA High- strength low-alloy steel with 1917g total mass including all subcomponents, with approximately 1475mm length and 200mm width.

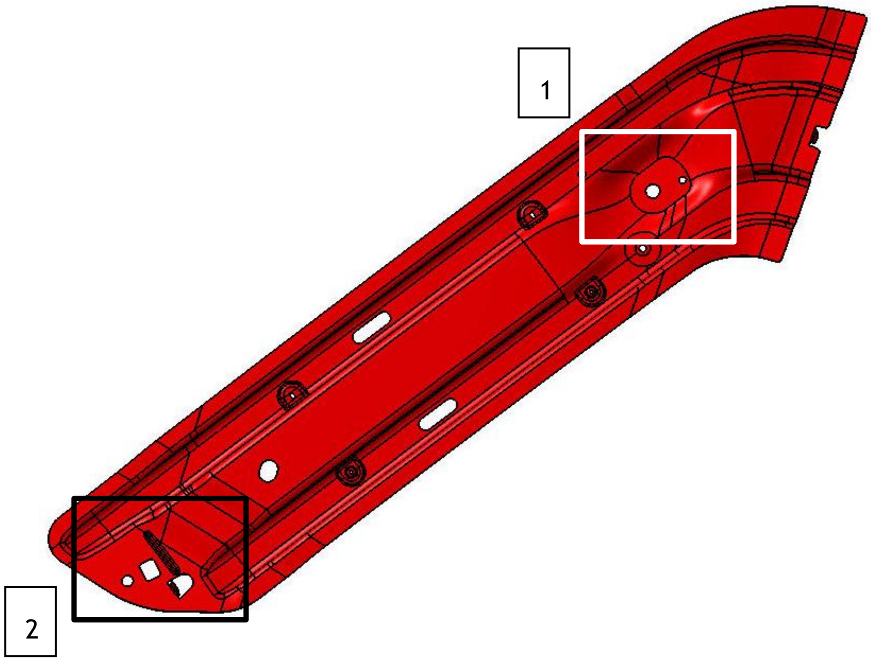

Figure 4: Seat belt guide rail.

This part is located in the upper area from the body structure, connecting the rear cross member and the C-pillar upper reinforcement, in order to guide the seat belt to the second row middle seat. It has also the important function retractor fixation point on the rear area (detail 2 Figure 4) and the D-ring (detail 1 Figure 4) near the C-pillar in order to provide the best security and comfort angle to the passenger.

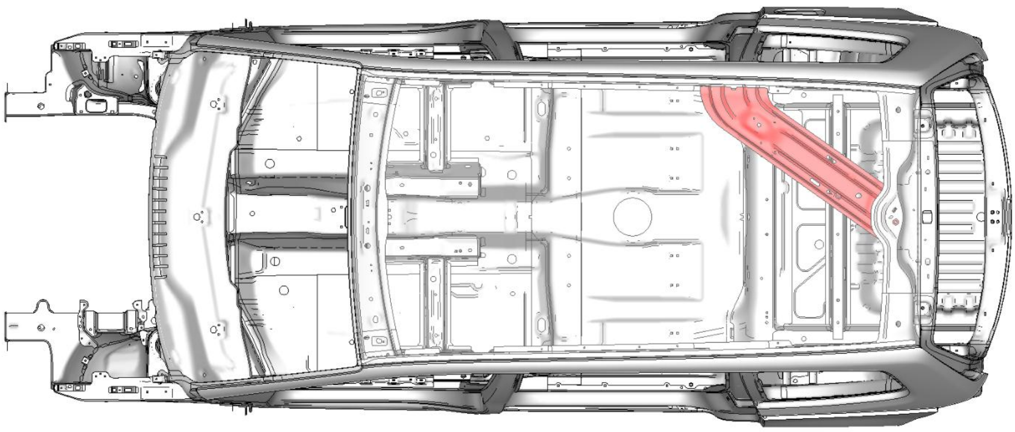

Figure 5: 2010 Volkswagen Sharan Body structure upper view and rail guide representation. (*Volkswagen AG*)

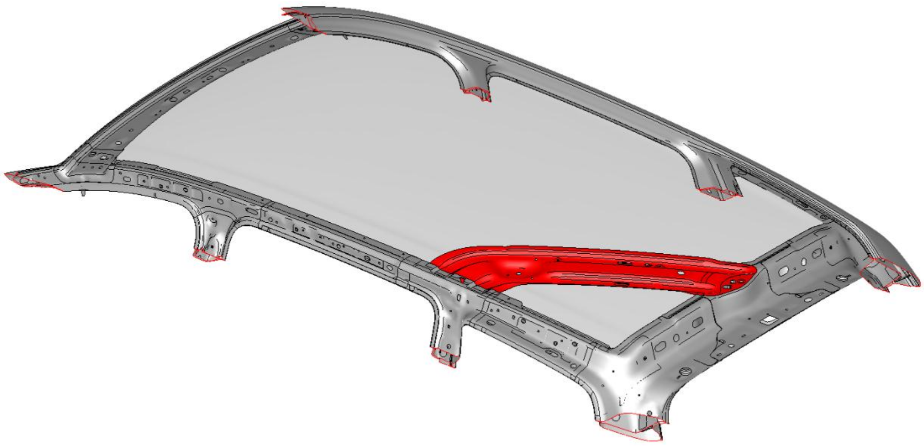

Figure 6: 2010 Volkswagen Sharan Body interior roof view and rail guide representation. (*Volkswagen AG*)

2.2 - Premises

One of the most important steps, when it is doing a project in cooperation with a big group as Volkswagen AG, it to clarify since the beginning which are the top premises, not only to use as guidelines during all the process as well as to be sure that no internal or external rules are forgotten.

For this project was established as premises:

- New improvements / ideas should be implemented using the Volkswagen AG internal development strategy.
- Software used to develop this project must be certified and according Volkswagen AG internal rules.
- The project feasibility must be proof under product improvement process rules.

2.3 - Benchmark

As is a Volkswagen goal to be always the best in class, one of the first steps taken was a Benchmark between the most quoted vehicles in market with similar characteristics to Volkswagen Sharan, comparing different concepts actually in production , as well as “pros and cons” of each one.

All the vehicles present in this comparative uses similar materials to them reinforcement as the welding / screw technologies are also similar. This aspect has a particular importance due to the fact that all manufactures tried to use the best design possible to achieve lighter concepts and not the lightest material existent in the market, controlling the development and production costs.

Volkswagen Touran shows a twin concept as the vehicle in study, where there is used a diagonal reinforcement in roof area between the rear cross member and the C-pillar in order to guide the seat belt. Also the fixation point from restraining and D-ring are in similar positions as Sharan. In terms of benchmark for this project it is not a relevant option to analyze because it is basically the same concepts with no new ideas that could be considered as an improvement.

Figure 7: Volkswagen Touran second seats row middle seat belt first point fixation.

Following the same line as Volkswagen Sharan and Touran, Ford Galaxy shows a diagonal reinforcement in roof area between the rear cross member and the C-pillar. This variant has the same characteristics as described before, including the fact that it is heavier as the concept presented in this study. As it is possible to see of this component has a minimal engineering design especially in terms of mass reduction. With a simpler design it is not possible to achieve the main goal of this project: reduction of total mass of the vehicle, which makes this option not relevant for this project.

Figure 8: Ford Galaxy second seats row middle seat belt first point fixation.

Audi Q7 and Opel Zafira, present a concept where the middle seat from the second seats row has an integrated seat belt. This approach is one of the more beautiful in terms of Design and one of the easiest one to use as final costumer point of view. However in terms of engineering this system obligates to reinforce all the underbody of the vehicle and also all the seat structure must be more robust in order to achieve the requested safety specifications. For this project, where it is supposed to improve an existing concept with the minimum costs possible and also reduce the final mass of the complete vehicle, this concept is not affordable, due to the fact that it would be necessary to redesign and reinforce the entire underbody's rear area and the complete second row seat structure. Automatically the investment costs would be higher as programmed as well as the total vehicle's mass.

Figure 9: Second seats row from an Audi Q7. (*Audi AG*)

Ford Grand C-Max, which is a direct concurrent from Volkswagen Sharan, it was choose to use a concept where the seat belt come directly from the C-pillar helped by a small welded reinforcement, as described on Figure 10. Due to design and ergonomic restrictions, this variant needs to have an asymmetric headlining because the seat belt would be available on the left side of the roof area, however and as well as Volkswagen Sharan, it seems to be user friendly.

In an engineering optic, this is one of the best concepts present in this benchmark. The reinforcement used is very simple to perform, safe as requested and also with a top lightweight design.

For this project, and as possible to see in the point 2.4 Constraining, this concept could not be applied, due to the fact that it would be necessary to change several Body structure components, as well as some plastic items in order to use it. Also the interior design of the vehicle must be completely changed. All these modifications would highly increase the final price necessary to its implementation and it wouldn't be profitable.

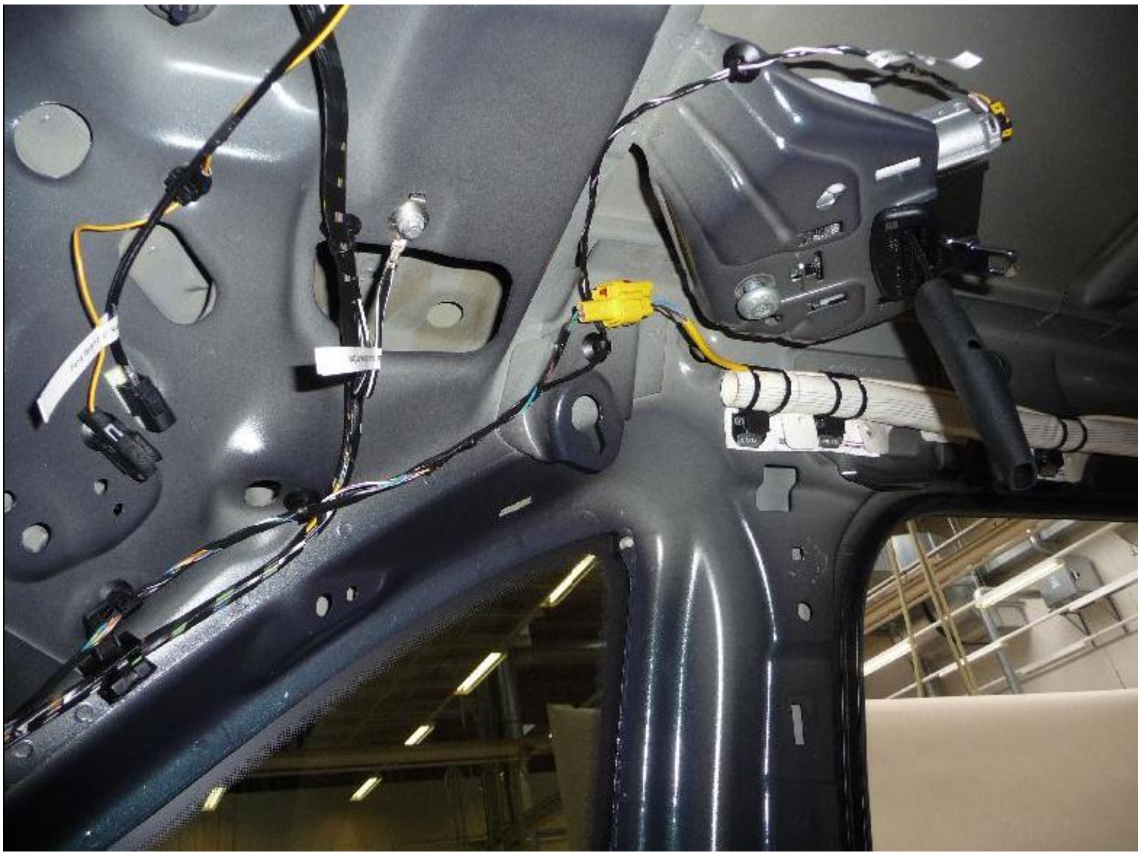

Figure 10: Second row middle seat's seat belt fixation concept from Ford Grand C-Max.

An also direct concurrent is Mazda 5, where the choose concept is in line with Ford one of the bests present in this Benchmark. Looking to the Design point of view, this variant needs also to have an asymmetric headlining like Grand C-Max.

Regarding engineering and comparing directly to Ford's concept, in Mazda the philosophy is almost the same with a small reinforcement in the rear quarter window area, however in this case it is not welded to the Body structure but it is screwed after paint. The reinforcement used is also simple, small and safe but this concept shows to be more expensive and possibly heavier due to that it is necessary to use additionally two screws and two nuts to fix the part.

For this project it would be not feasible to use this concept regarding the same aspects as described before to Ford Grand C-Max.

Figure 11: Second row middle seat's seat belt fixation concept from Mazda 5.

Opel Meriva presents the best concept studied in this Benchmark. Also like Ford and Mazda the interior Design must be asymmetric and also the ergonomic is not the best aspect in this variant due to the fact that the seat belt is not nearby the passenger; however in terms of engineering design this is the simpler, cheaper and lighter concept. In this case Opel chose to use a "hole" in the rear roof cross member. This area is already reinforced, because is a crucial structural area of the vehicle. With this it is not necessary to increase the vehicle's costs and mass with additional parts in order to achieve the same safety results as the other concurrent.

However for this project it would be not feasible to use this concept not only regarding the financial aspects presented on Ford Grand C-Max and Mazda 5 situations, but also because Volkswagen Sharan is a B class MPV, bigger than Opel Meriva that is A-class vehicle. These aspects would make not possible the use the third row right seat when the second row middle seat is occupied, due to the necessary angle to the seat belt.

Figure 12: Second row middle seat's seat belt fixation concept from Opel Meriva.

Nissan Qashqai adopted a similar situation as Opel, using the area from rear cross member to fix the seat belt. In terms of benchmark the "pros and cons" are exactly the same as the previous model, and for this particular project, it would not be feasible to implement.

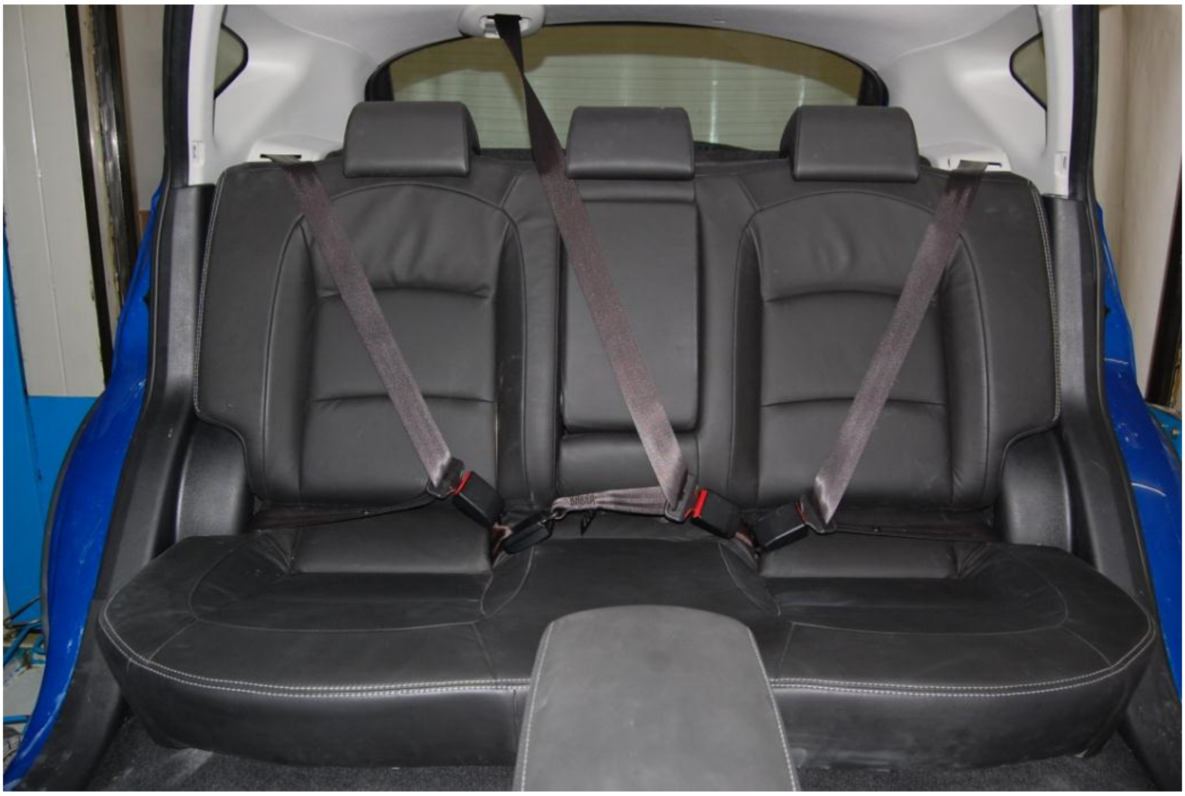

Figure 13: Second row middle seat's seat belt fixation concept from Nissan Qashqai.

2.4 - Constraints

Even trying to have the best possible result in mass and price improvement, there are several constrains that should be considered before starting to analyze or design the improved part.

2.4.1 – Design Constraints

Exterior and interior Design is a top premise in order to have a more attractive vehicle to the costumer and consequently increase the sales, all the small details are extremely important.

Figure 14 shows the interior of the 2010 Volkwagen Sharan. All the details where taking in account in order to offer a robust and beautiful vehicle for all the family, offering also the entire main item in the correct place concerning to ergonomic and a “user-friendly” perspective.

Figure 14: 2010 Volkswagen Sharan interior seats perspective with particular attention to the second seat row middle seat belt. (*Volkswagen AG*)

Taking a special attention to the Figure 14, the second seat row middle seat belt has not the best possible design, however its position guarantee the most effective safety to the passengers as well as offers one of the best ergonomic solutions in the market.

As it is possible to visualize in the Figure 15, the seat belt roller is placed on the upper area from the center of the vehicle between both seats on the third row inside the headlining “bubble”.

Figure 15: 2010 Volkswagen Sharan interior seats perspective, with special detail to the “bubble” where is located the seat belt retractor. (*Volkswagen AG*)

Considering a relevant change in the actual concept, it would be necessary to replace the actual “bubble” to one of the sides, which would create a not harmonic design in the vehicles interior and consequently it will be against the “Anmutungphilosophie” (passion to the detail) from Volkswagen’s Group.

2.4.2 – Body Constraints

Analysing now the Body structure and the influence of a possible geometry improvement in the rail guide, all significant new design would request changes on some connected components and automatically higher investment costs.

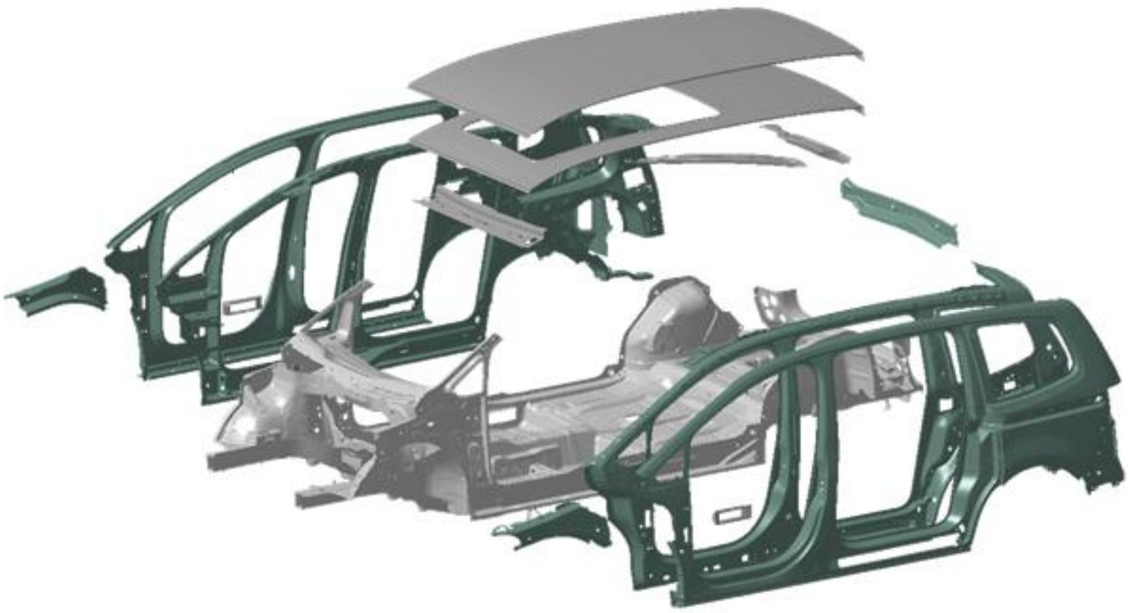

Figure 16: 2010 Volkswagen Body Structure. (*Volkswagen AG*)

As described before, the part in study connect rear cross member to C-pillar reinforcement. In order to keep these components unchanged, the connection points and contact areas must be kept, if not and as presented on Figure 17 and Figure 18, the marked areas should be redesign in order to be adapted to the improved geometry.

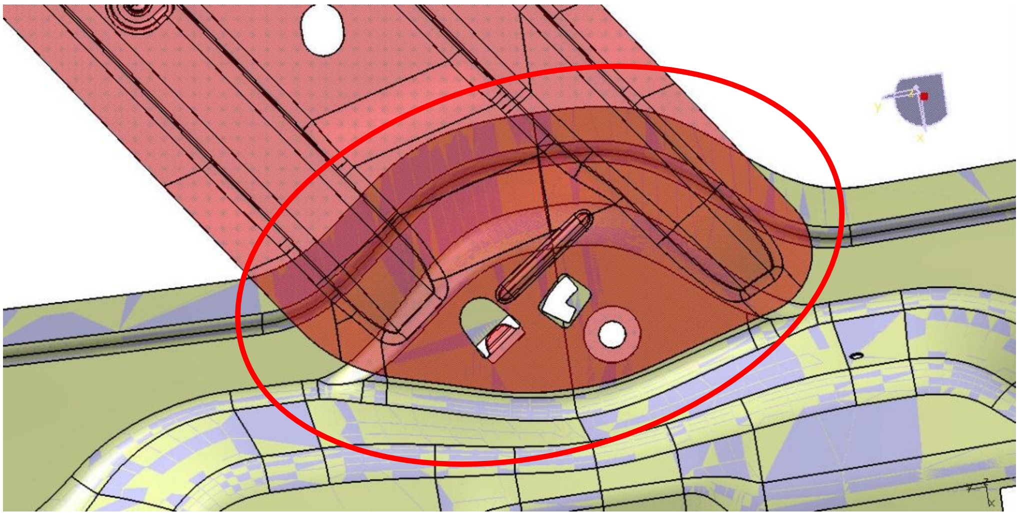

Figure 17: Connection between rail guide and rear cross member.

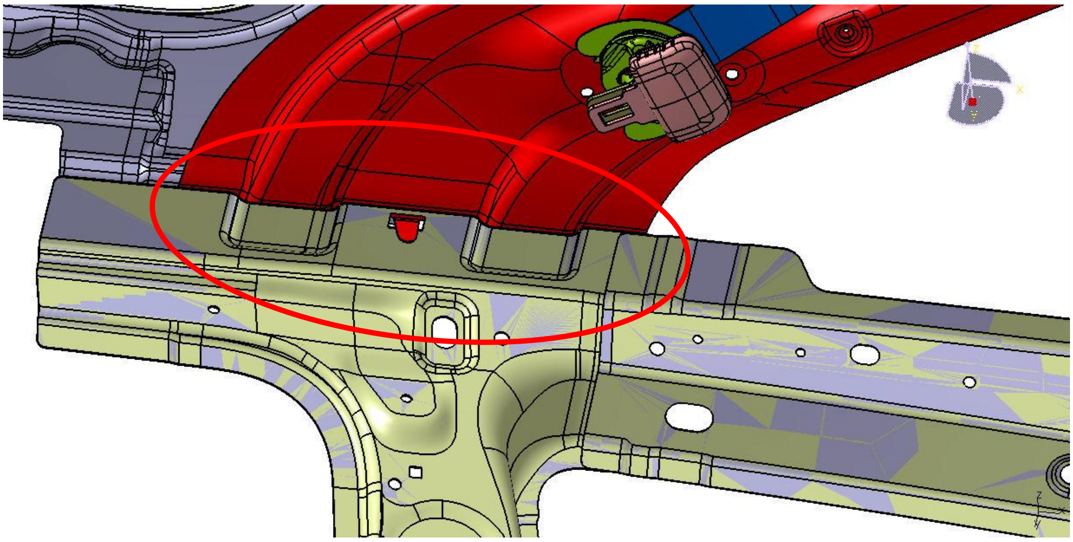

Figure 18: Connection between rail guide and C-pillar.

Also and as refereed before, the roof has a contact support area to the rail guide. If the improved design takes the same concept as for example Opel Meriva, the contact area will disappear and automatically would be necessary to develop another support mechanism. This situation would imply high investment and creation of new parts, which could increase the vehicle mass.

Other approach to take in mind is a change from actual part's serial material, where instead of traditional steel; it would be possible to use a lightweight material like aluminum or high resistance composite.

High resistance composite could have the necessary characteristics regarding safety but are not feasible to use in a vehicle of this segment. The investment costs are not possible to support and also the price pro part is also over budget, which would also increase significantly the final price of the vehicle.

Regarding materials like aluminum, it could be more feasible to use. Even though investment is higher than normal steel, this variant is acceptable for this segment and the price pro part could be also absorbed in the final price of vehicle. This is clearly a way to explore, however in this project, where Volkswagen Sharan is a serial vehicle, it would be necessary to change the entire fixations concept from this component to the Body structure and automatically the current production process.

As known, it is not possible to weld aluminum to normal steel, it is necessary to rivet them to a steel structure or use high resistance structural glue. Regarding these restrictions, and as referred before it would be necessary to redesign the entire fixation concept and automatically, change all the construction line regarding this area of the vehicle.

Consequently this situation would request a high investment cost, which is not profitable to this project. However, this is one of the best options in order to have a lightweight vehicle with a reasonable price for these types of segments, and to prove that, brands like AUDI have already some vehicles like Audi A2 / A6 / A8 / Q7 and TT, developed with aluminum parts.

2.4.3 - Trim Constraining

Considering in this case all the final assembly or vulgarly called, Trim parts, any major change in the component in study will affect other critical parts, which could force to redesign them.

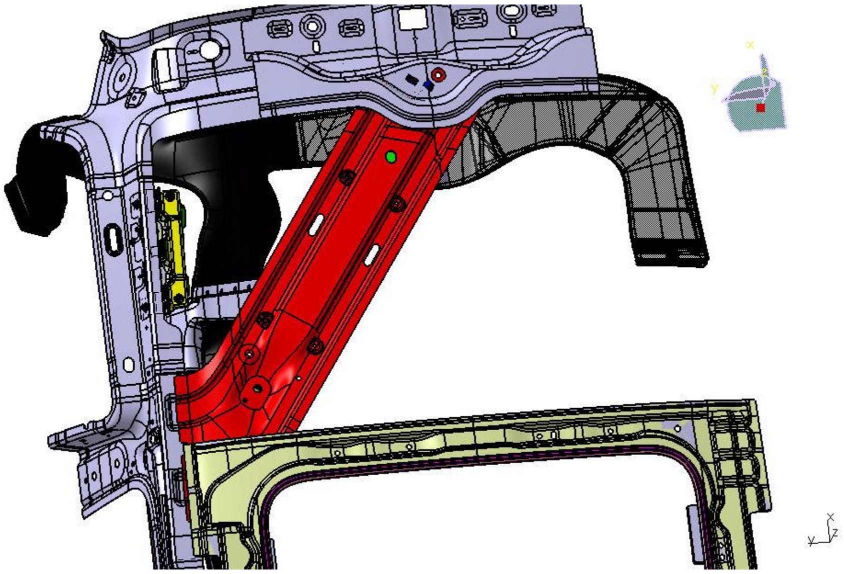

Figure 19: Volkswagen Sharan virtual representation from Body structure with Trim parts involved in constraints.

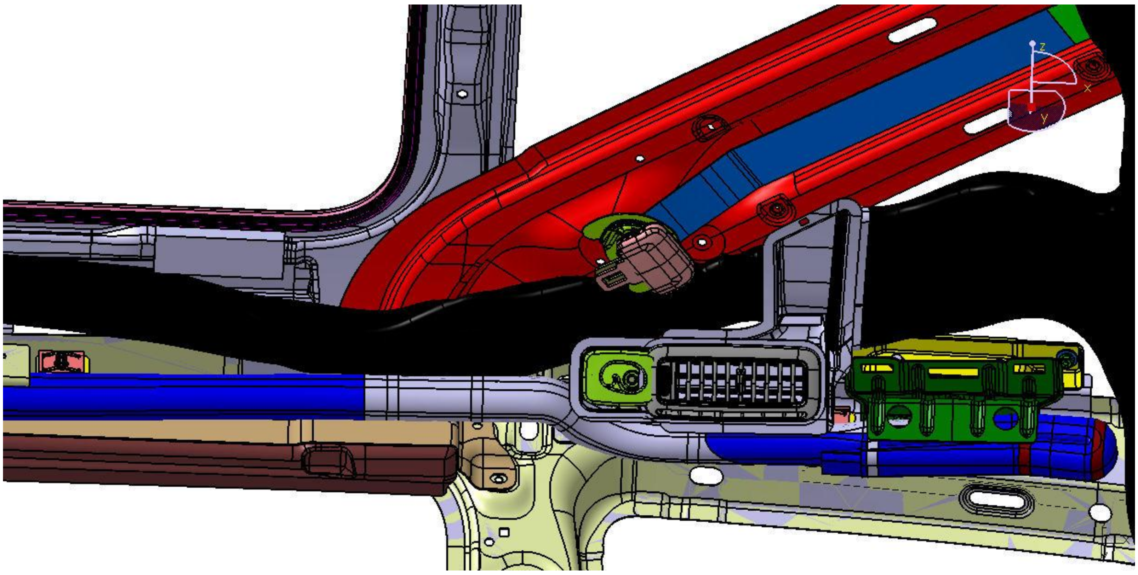

Figure 20: Virtual representation from C-Pillar with Trim parts involved in constraints.

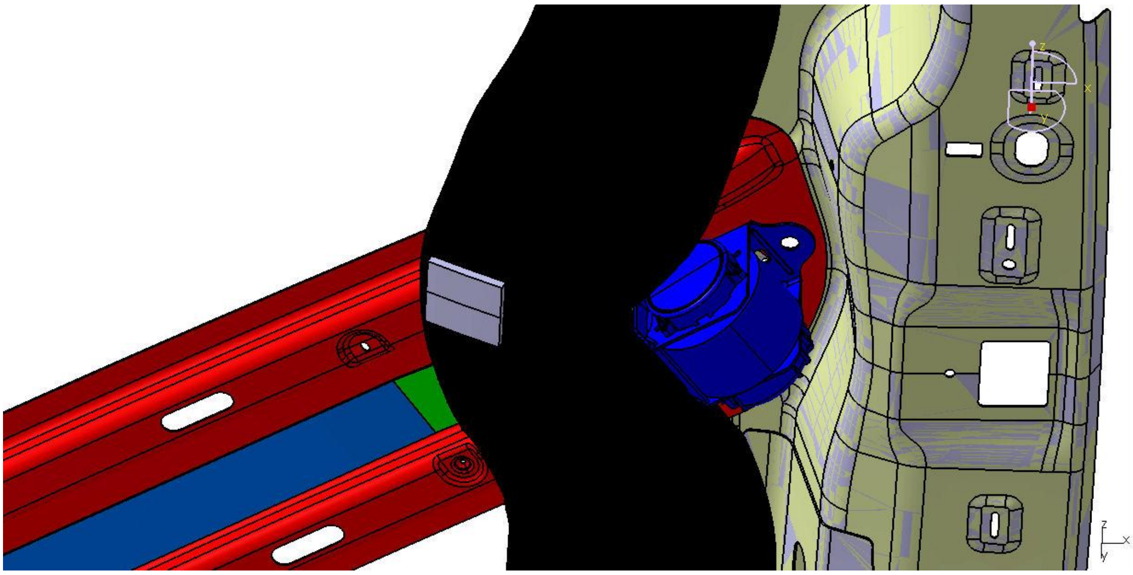

Figure 21: Virtual representation from rear cross member with Trim parts involved in constraints.

Taking a careful look to the three main areas of the rail guide presented in the pictures above, it is possible to visualize that this body part is surrounded by all the main roof Trim parts.

Starting to analyze the first connection point in the C-pillar upper area (Figure 20), the rail guide has the entire rear seat's airbag system, the air conditional channels, the sliding door upper system, the open roof system and also not directly to the rail roof system nearby.

In order to change the guide rail, it would be necessary redesign all that systems, which means a huge investment, that would not be possible to recover by an improvement on the rail guide.

Regarding the second main section, where the rail guide is welded to the rear roof cross member (Figure 21), the problematic is similar as described before.

Despite of there are less parts to be changed, there are some other problems that could not be perceptible at a first view.

This vehicle has a very big interior volume which means that in a first instance it is more difficult to have an optimal air circulation inside the vehicle. However and due to mass distribution and reduction on the vehicle, there is only one air condition pump located on the right side of the vehicle; each means that in order to have the same air flow to all passengers the air conditional channel must have a specific geometry and design. If the rail guide changes its geometry in the rear area, all these channels must be redesign in other to guarantee the same air flow, which means one more time, a dramatic investment.

Analyzing now the part itself and all the components that are directly fixed to it (Figure 22), there are 2 constrains.

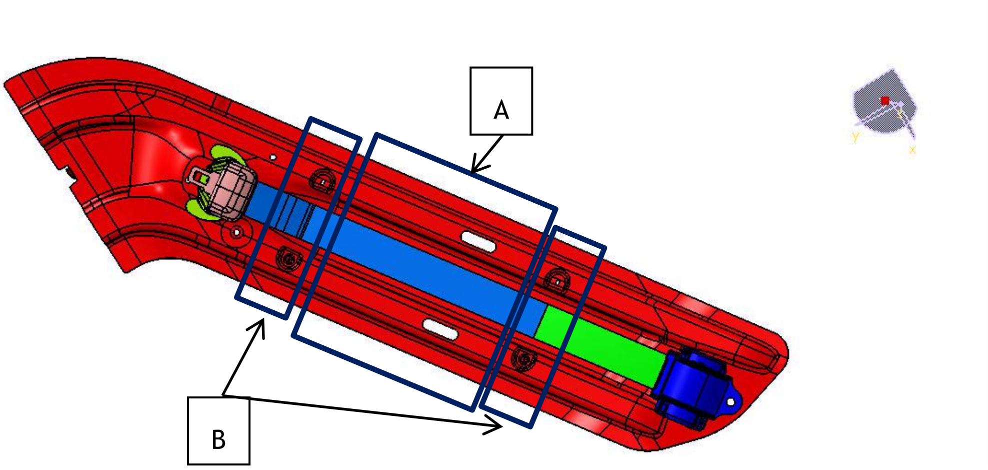

Figure 22: Rail Guide with seat belt assembled.

It is necessary to fix the seatbelt and due to this, the middle area of the rail guide (area A Figure 22) must but large enough in order to have some free space and let the belt to move without any restrictions.

Second point are the 2 little guides that are fixed to the part in study, which are used to give some pre-tension to the seat belt and also help to fix it in a case of impact.

Due to this situation, if the 4 fixation (area B Figure 22) holes changed, it would be necessary to change also the geometry of those guides.

3

Characteristics of the part in actual production

Abstract: In this chapter, it is described with maximum detail all aspects regarding actual part characteristics, starting with material properties, stamping production process and welding processes not only used to produce the guide rail as a complete group of parts as well as to implement it in the complete Body structure. Processes like cold stamping and projection and spot weld welding, are technically described in order to have a better understanding about their basic functions.

3.1 - Introduction

The Body part in study is currently produced by the company Gestamp Portugal – Gestão e Industria de estampagens metálica, Lda in Aveiro, Portugal, which is owned by an international group dedicated to develop and produce metallic components to Automobile Industry. Actually, Gestamp Group is operational in 18 different countries, with 60 plants and 13 development centers, employing more than 13200 people.

In this chapter will be study all the actual part characteristics, taking special attention to material, actual stamping and welding process not only in the part but also in the complete Body structure.

This chapter is largely based on Simech Simulation et Technologie (2001). Introduction to Sheet Metal Forming Processes. Paris, France.; Dayton Progress Corporation (2003). Stamping Basics Fundamentals & Terminology. Ohio, USA, as well as on Ruukki. Resistance Welding Manual. Helsinki, Finland.

3.2 - Material Properties

The component in study is made of high-strength low-alloy steel (HSLA) for cold forming HC340LA according to the standard DIN EN 10268:2006 - Cold rolled steel flat products with high yield strength for cold forming.

HSLA steels is a type of alloy steel that, comparing to common carbon ones, provides better mechanical properties and greater corrosion resistance, thus allowing advantages in terms of reduced component thickness and mass.

The HSLA steel HC340LA used in the construction of part in study has the following chemical composition (*DIN EN 10268:2006*):

Table 1: Chemical composition in % of grade from the low alloy steel HC340LA.

C	**Si**	**Mn**	**P**	**S**	**Nb**	**Ti**	**Al**
max 0.1	max 0.5	max 1.1	max 0.025	max 0.025	max 0.09	max 0.15	min 0.015

The low alloy steel HC340LA has the following mechanical characteristics (*DIN EN 10268:2006*):

- Tensile strength: 400-500 MPa
- 0.2% proof strength: 340-410 MPa
- Minimum elongation Lo = 80 mm: 22%

Table 2: International equivalent grades from the low alloy steel HC340LA.

USA -	Germany DIN, WNr	Japan JIS	France AFNOR
Gr.50	ZStE340	SPFC490	E315C

The HSLA chemical composition is tuned for providing the required mechanical properties. The percent of carbon is kept between 0.05 to 0.25%.

Small amounts of other alloy elements (therefore the “low-alloy” designation) such as copper, nickel, niobium, nitrogen, vanadium, chromium, molybdenium, titanium, calcium and rare earth elements, are added to control the microstructure and grain size, and to improve corrosion resistance.

The use of In case of copper, titanium, vanadium and niobium, provides a decrease in grain size in a ferrite-pearlite microstructure, and a consequent increase in yield strength. Normally yield strength between 250-590 MPa can be achieved.

Although the increase yield strength allows a thickness reduction, usually the manufacturing conforming processes would require 25-30% more power than for normal carbon steels.

Regarding silicon, nickel, chromium and phosphorus, they are added to increase corrosion resistance, on the other hand zirconium, calcium and rare earth elements are added to increase formability properties.

With small variations in the percentages of the alloy elements the steel can meet requirements according to the following classification:

- Weathering steels, which have better corrosion resistance.
- Control-rolled steels or hot-rolled steels, which have a highly deformed austenite structure that will transform to a very fine equiaxed ferrite structure after cooling.
- Pearlite-reduced steels, which have a low carbon content and also residual or no pearlite, but rather a very fine grain ferrite matrix. This type is strengthened by precipitation hardening.
- Acicular ferrite steels, which are characterized by a very fine high strength acicular ferrite structure with a very low carbon content and good hardenability.
- Dual-phase steels, which have a ferrite microstructure that contains small, uniformly distributed sections of martensite. This microstructure gives low yield strength, high rate of work hardening and good formability.
- Microalloyed steels, which contains a small addition of niobium, vanadium and /or titanium to obtain a refined grain size and/or precipitation hardening.

Due to the good strength-to-mass ratio and corrosion resistance, this type of steels is used in vehicles manufacturing, cranes, bridges, roller coasters and other structures.

3.3 - Metal Parts Cold Forming Stamping Process

The Body part in study as said before is made by HC340LA steel and in its production it is used the popular cold forming stamping process.

This kind of process is easy to use and allow automobile industry to have high resistance metal parts with the cheapest price as possible, considering also, the high initial investment necessary to implement a new press and the necessary tools, which could be absorbed by the total volume of parts produced. Mainly advantages from this kind of process are:

- Stamping production efficiency, easy to operate, easy to implement mechanization and automation.
- High accuracy regarding size and shape and good surface quality
- Longer life of the dies
- Smooth material feeding, product removal and scrap disposal

In order to have a better understanding regarding this kind of technology, it is important to have a short description about the main characteristics of this process:

In 1985, the development cycle of a stamped part looked like more a mess to a sequential series of operations starting with a single style design, which had a 42 months lead time starting with the product design.

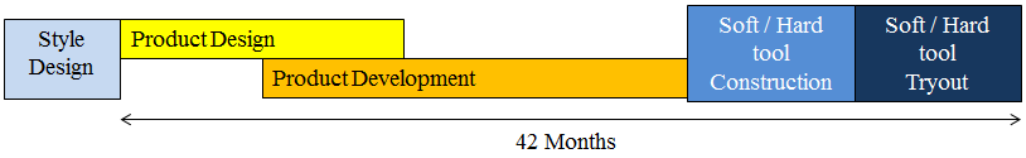

Figure 23: Development cycle of a stamped part tool in 1985.

Nowadays, the perspective is completely different, where key decisions are taken regarding different factors and alternative choices, always with the maximum efficient production as possible. In order to help companies to reduce investment costs with necessary manpower and physical tests, Computer Aided Engineering, usually known as CAE, which allows higher information transfer and process simulations, are used. This computer simulation processes are considered as rough real simulations to have the first approach of the developed component with a smaller investment and also with a smaller lead time, due to the fact that it is not necessary to produce prototype parts to use in tests at this phase. Also these kinds of tests give already great feasibility results in order to proceed with the project.

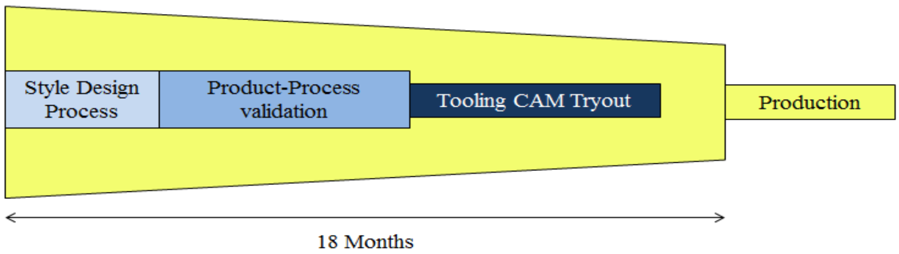

Figure 24: Nowadays development cycle of a stamped part tool.

Regarding stamping process, it is possible to say that it is, like all complex systems, composed by hardware and software.

In the Hardware group, it is included in this group all the characteristics that cannot be changed from one operation to another. On the other hand, Software is all the characteristics that are changeable from one operation to another in order to have the requested part.

Table 3: Components of a stamping design

Hardware	Software
Press Tools	Press set-up Material Lubrication

Considering the Stamping process, the first Hardware part to analyze is the stamping press, which is a machine that houses the stamping tools (tooling) and carries them around according to the kinematics indicated by the user (process set-up) (*INTRODUCTION TO SHEET METAL FORMING PROCESSES, Simtech, 2009*).

Understanding the stamping press that would be used to a specific operation can provide some important information regarding:

- Value and distribution of restraining forces
- Tool deformation caused by stamping forces
- Contact and/or gap between tools and blank

Although, in many cases during the die design, the stamping press where this specific die will be used is not known. With that not only the design process should be robust enough to be implemented in a larger range of presses.

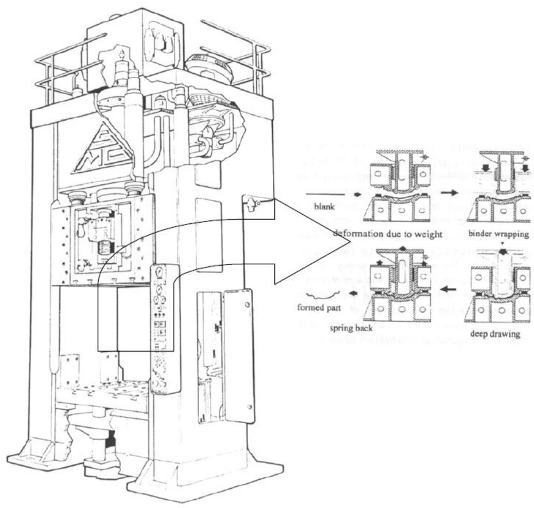

Figure 25: Schematic of a stamping press and diferent dies / operation used to have a formed part. (*Simtech, 2009*)

Getting deaper in the understanding of a stamping tool, it is useful to analyze the called *Process Design* which is "the ensemble of operations leading from the design geometry to the dieface" (*Simtech, 2009*).

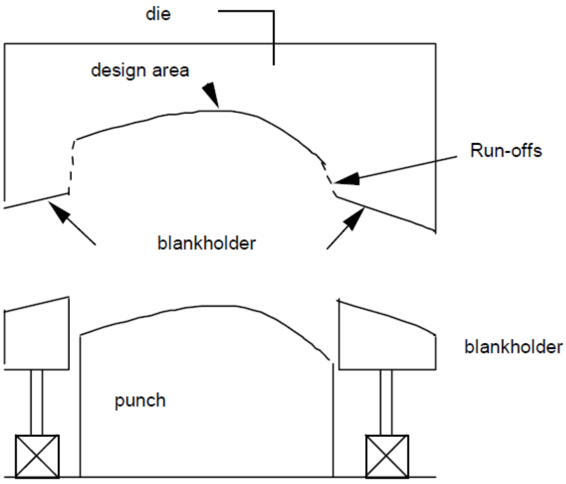

Figure 26: Schematic of a stamping tool. (*Simtech, 2009*)

As described in "Introduction to Sheet Metal Forming Process, Simtech, 2009", a stamping tool can be divided in the following main parts:

Design surface, which is designed to fit in the vehicle (after trimming).

Blankholder surface, which holds the blank before the forming operation, including the restraining.

Production surface/run-offs, which is a junction between the two former surfaces, protecting the design surface and controlling material flow.

Dieface, which is the set made by the Run-offs + blankholder.

Going from a macro view of the stamping process to a more technical point of view, it is possible to analyze that a sheet formed part is usually obtained not only from a single stamping operations but through a considered number of them.

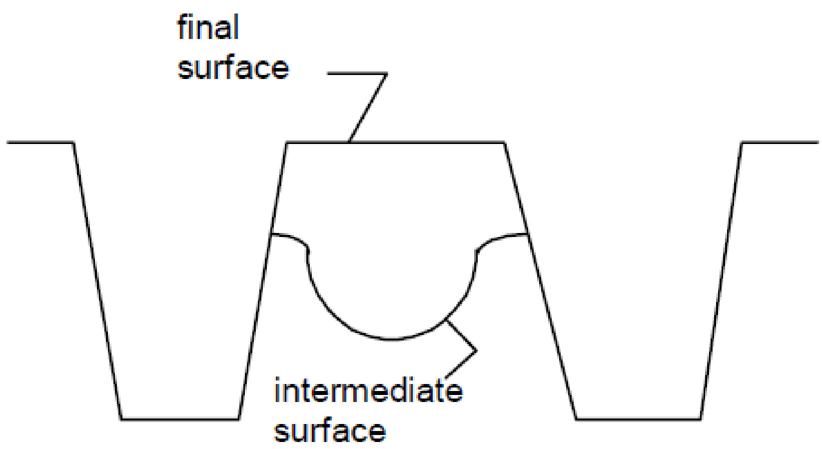

Figure 27: Schemtaic of a single operation and behaviour of the formed part. (*Simtech, 2009*)

Starting a Stamping process design, it is important to have some deliverables of the process in mind.

Dieface design, where designs are delivered under CAD format. Engineers design the specifications for each different geometry of each dieface tool.

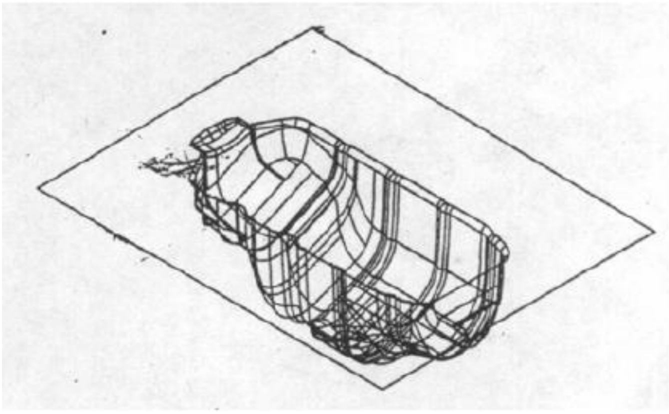

Figure 28: Dieface geometry of a specific station. (*Simtech, 2009*)

Cutting pattern profile is also delivered in drawing or CAD format. It specifies the geometry of the punching tool prior to the actual stamping operation.

Production constraints usually force the use of simple cutting patters. In practice, some basic shapes are used:

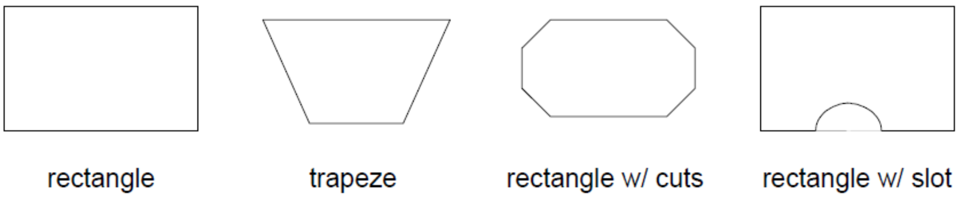

Figure 29: Simple cutting patters normally used in prduction. (*Simtech, 2009*)

Stamping cycle is the description of all the operations leading to the production of the finished stamped part.

A typical stamping cycle could include:

• One or more stamping stations

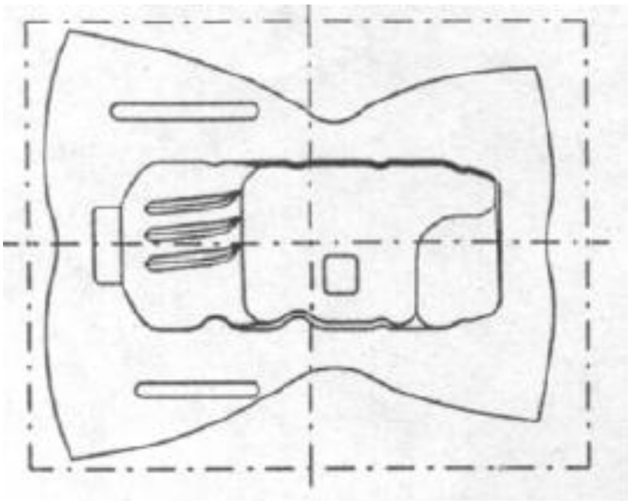

Figure 30: Stamping station. (*Simtech, 2009*)

• One coining station

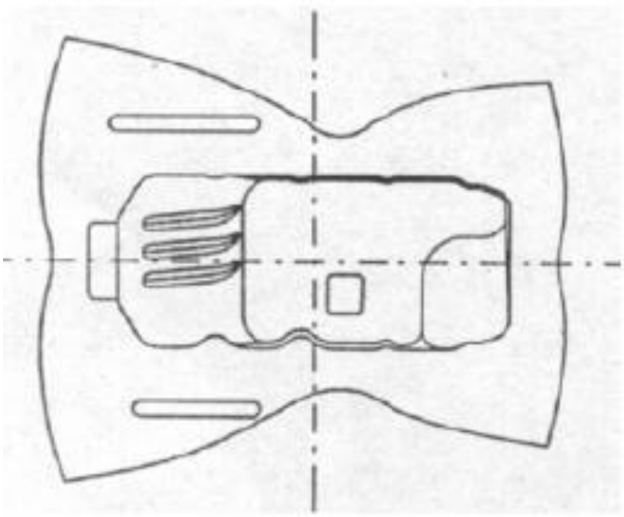

Figure 31: Coining station. (*Simtech, 2009*)

• One trimming station

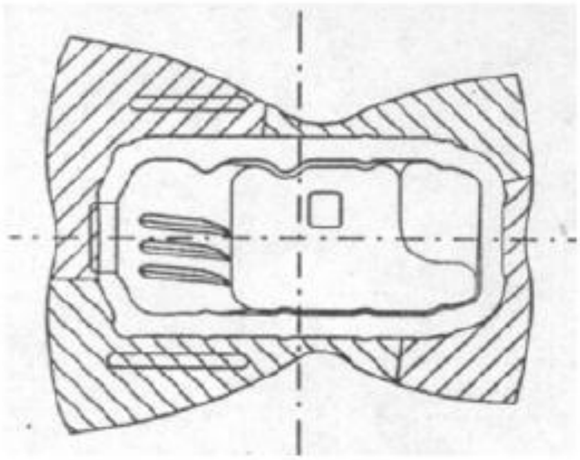

Figure 32: Trimming station. (*Simtech, 2009*)

• One punching and flanging station

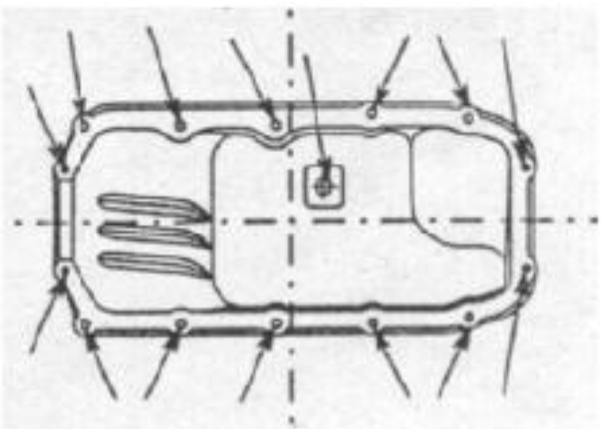

Figure 33: Punching and flanging station. (Simtech, 2009)

In order to understand the complex system of surfaces in an actual dieface, it is not necessary to go deeply in all the details. Some basic geometry features, described above, can be identified as (*Simtech, 2009*):

• Stamping direction, which is identified on the basis of minimum undercut, inertia moment or straightness of projected characteristic lines.

• Punch radius line, identified after flange development and protection.

• Die entry line, which joins the punch line to the blankholder, with an opening angle to avoid undercuts.

Blankholder, which can be developable (conical or ruled) or quasidevelopable. Non-developable blankholders may give rise to wrinkling problems during the holding phase.

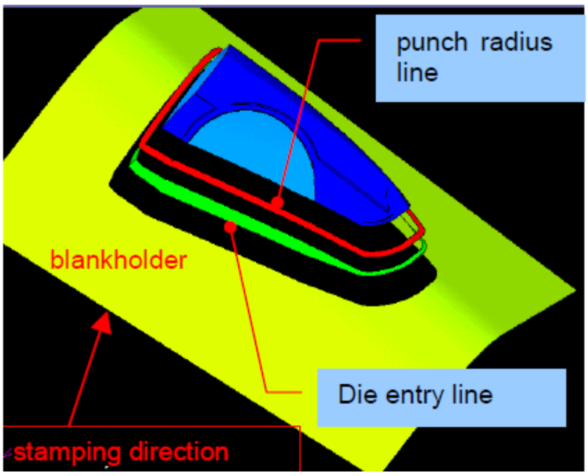

Figure 34: Basic geometry featurs identified in a dieface design. (*Simtech, 2009*)

Analyzing now the rail guide stamping process according to what was described before, it has currently a 4 steps process included in 1 press tool plus a first cut operation, where the original coil is cut with the requested geometry, in order to have the necessary flat blank for production. The stamping process steps for the component in study are shown on Figure 35 and Figure 36.

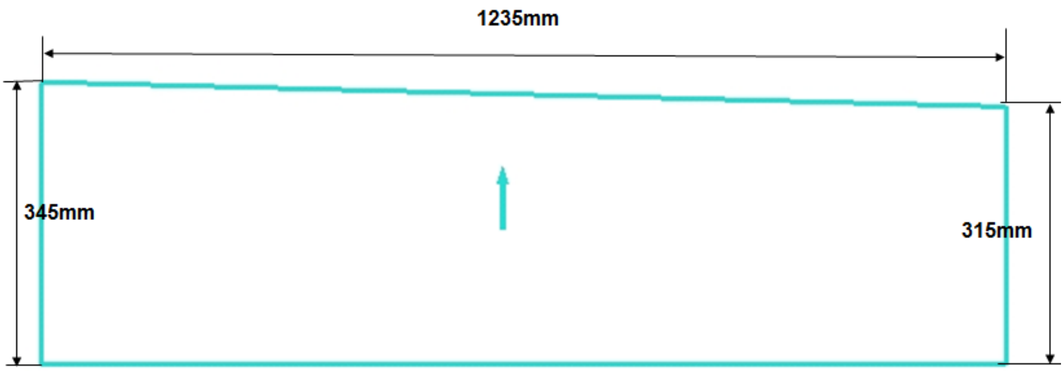

Figure 35: Flat blank geometry for actual part's stamping process with 1mm thickness.

The coil cutting operation in order to create the necessary flat blank is considered as the first stamping operation.

Figure 36: Actual part press tool with 4 different operations. (*Gestamp Portugal*)

Considering the first step as coil cutting, the second step, presented on Figure 36 with number 2, would be the forming stage, where the main volume of the part is created and due to the fact that this shape is relatively simple, it is also possible to make not only the main volume but also the correct geometry of the part.

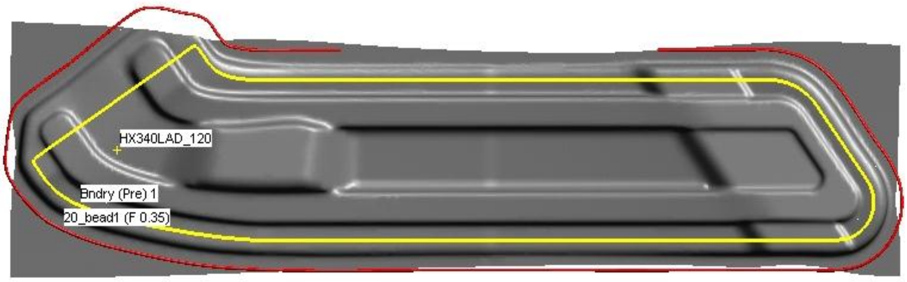

Figure 37: First stamping stage: Main volume and geometry. (*Volkswagen Stamping Simulation Department*)

In this operation the original flat blank should adapts to the blankholder shape, by gravity fall.

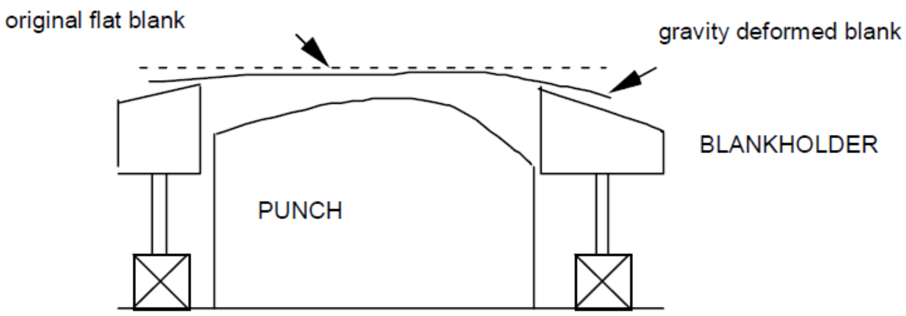

Figure 38: Gravity Fall phase of a stamping operation. (*Simtech, 2009*)

Second phase is holding, where the die pushes on the blankholder and press the blank. During that, it is also controlled the shape of the flat blank and the contact between the blank and the punch.

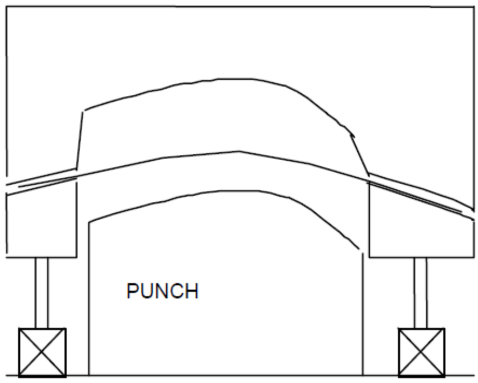

Figure 39: Holding phase of a stamping operation. (*Simtech, 2009*)

After holding is the Forming phase, where the die goes down until it press completely the flat blank onto the punch.

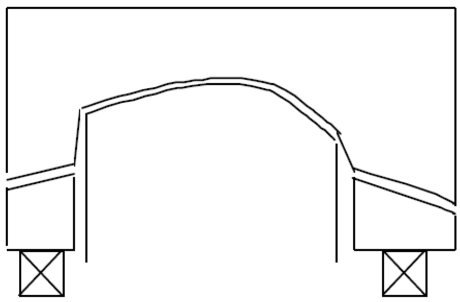

Figure 40: Forming phase of a stamping operation. (*Simtech, 2009*)

Due to the fact that forming operation is one of the most important phases during a stamping operation, it must be divided in two parts in order to have a better understanding.

First part is where the volume of the part is created. This is mostly controlled by the production surface and by the restraining system.

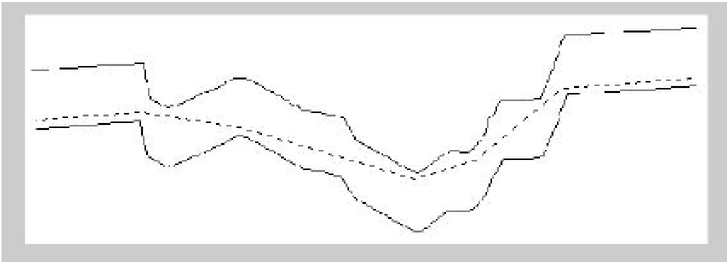

Figure 41: Fisrt part or Volume creation during a Forming phase. (*Simtech, 2009*)

After creating the part's volume, the geometry details must be formed. This is controlled by the geometry of the part.

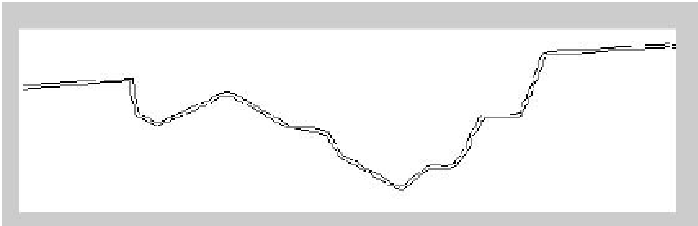

Figure 42: Second part or Geometry cretion during a Forming phae. (*Simtech, 2009*)

After forming phase, it is necessary to create the holes and cutting the trim flanges. Also due to the part's geometry and the number of holes, this step is made in 2 different operations, where operation 3 open the holes and cuts 5 flange areas and the operation 4 cuts the remaining ones. It would be possible to analyze all the cutting process in one operation, however and due to the fact that the part is not completely plan, there are different cutting directions, which mean several knives with different movement orientations should be implemented. During the stamping process and due to these different orientations, the knives would collide to each other, which make this possibility not feasible.

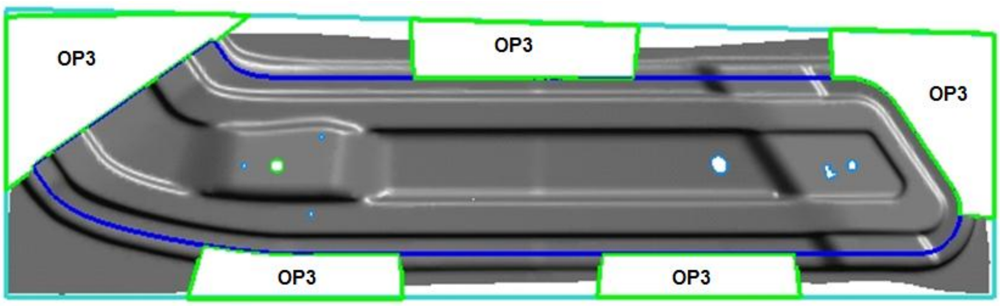

Figure 43: Operation 3 from the stamping process, where holes are opened and 5 trim flanges cut. (*Volkswagen Stamping Simulation Department*)

Regarding forming operations there are several types that could be possible to perform in order to reach the needed geometry. Analyzing in detail the operation 3 on Figure 43, there are several different holes to be performed.

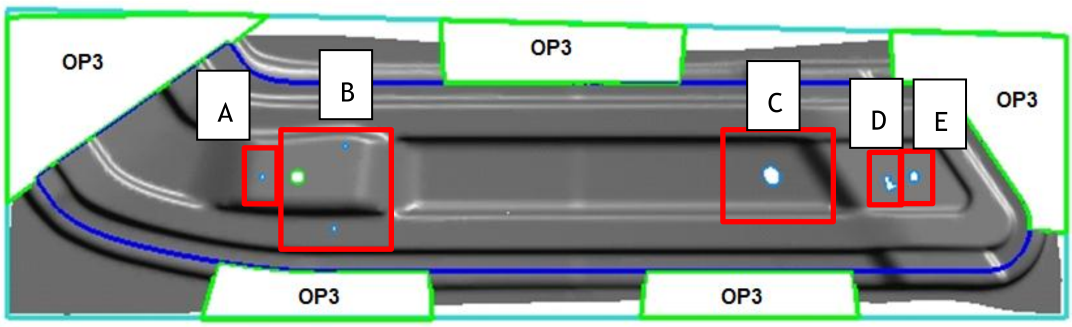

Figure 44: Part geometry on operation 3 with detailed holes to be implemented. (*Volkswagen Stamping Simulation Department*)

Considering the details showed on Figure 44, the holes A, B, C and E are done using perforating technology, where holes are made by removing a slug. When perforating in a stamping operation, a punch shears and breaks a slug out of the intended part material. The punch pushes the slug into a die hole (matrix). The matrix hole is larger than the punch point. A constant punch-to-matrix clearance is maintained around the entire punch point.

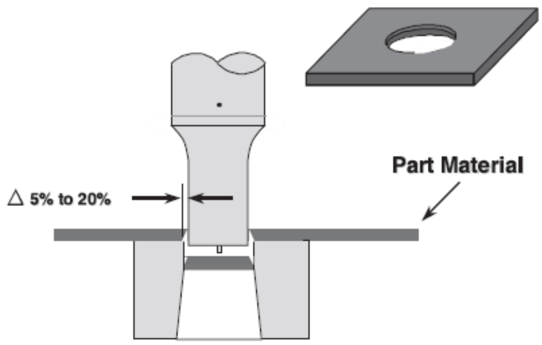

Figure 45: Perforating operation. (*Dayton Progress Corporating, 2003*)

To calculate stamp force requirements for perforating, multiply the part material thickness times the length of the cut, or perimeter of the hole, times the material shear strength. Determine the perimeter of a round hole by multiplying pi times the hole's diameter:

$$P = T * L * S$$

Where,

T is thickness of Part Material

L is the length of Shear

S is the shear strength of the Part

P is the perforating Force.

Also important to refer that shear and tensile strengths for most materials are not the same, taking some examples:

• Aluminum shear strength is approximately 50% of its tensile strength

• Cold-roll steel shear strength is approximately 80% of its tensile strength

• Stainless steel shear strength is approximately 90% of its tensile strength

It is important to include the stripper pressure when calculating die stamping force requirements. Stripper pressure should be at least 8% of the perforating force. Some die manufacturers require stripper pressure as high as 25% of the perforating pressure. (*Stamping Basics Fundamentals & Terminology, Dayton Progress Corporating, 2003*)

Regarding the detail D on Figure 44, it is possible to visualize that it would requested a different type of technology to perform it.

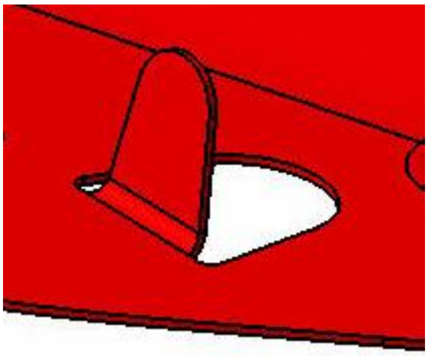

Figure 46: Zoom view from detail C on Figure 44.

For this case, is used Lancing technology, where is created a tab within the part. No slug is removed. This operation commonly incorporates a single shear angle on the face of the punch.

Normal perforating clearance is applied to areas of the tab to be cut free. The portion of the tab that remains connected is bent to the desired angle over the matrix. Clearance between the radius portion of the punch and matrix equals the material thickness.

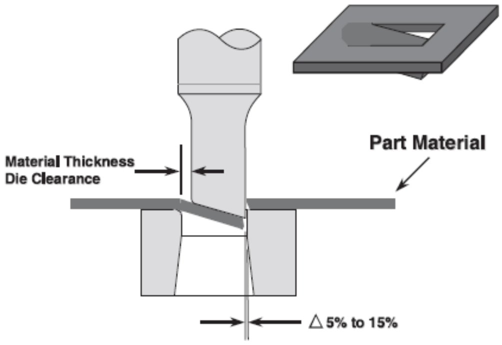

Figure 47: Lancing operation. (*Dayton Progress Corporating, 2003*)

Not presented on Figure 44, but also important to refer are the seat belt guides fixation points. On Figure 48, it is possible to visualize the requested geometry for this area.

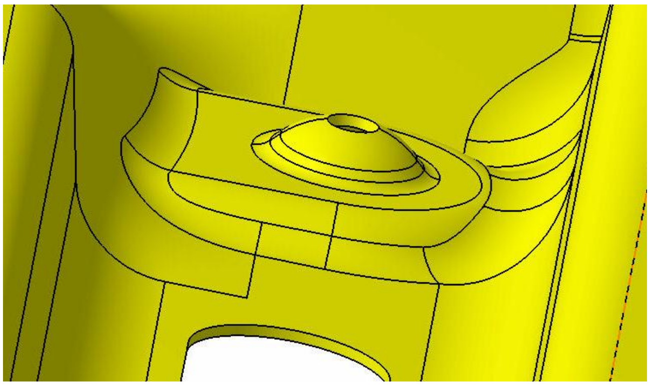

Figure 48: Detailed view from seat belt guide fixation.

In this case, Shear Angles is the best solution to implement, reducing punch load and improve slug control by using shear angles on the punch face. This kind of operation could have many configurations.

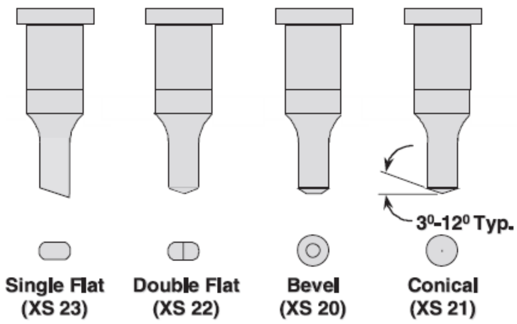

Figure 49: Shear angles configurations. (*Dayton Progress Corporating, 2003*)

Considering the examples presented on Figure 49, for the part in study it was choose to conical shear to perform the requested geometry, due to the fact that it is the best configuration when perforating with a round punch. Load reduction is greater than with the bevel shear. Wear evenly distributes around the point, and the slug deforms enough to minimize slug pulling.

For operation 3 and 4 is important to refer that during trimming process when not necessary flanges are removed, and due to plastic deformation some stresses locked through metal thickness are left in the part, originating a different final geometry than the one that was on the tool after the extraction from the tools. Regarding this phenomenon, it is important during the tool design to incorporate the springback factor and when it should be implemented, which could vary depending on which material would be used, and not working with the nominal geometry. When the springback is before trimming, could be important to analyze it due to some changes on tool's design and robots position during the process. Also, when it is after trimming may change the shape of the part to the point that it is impossible to assemble.

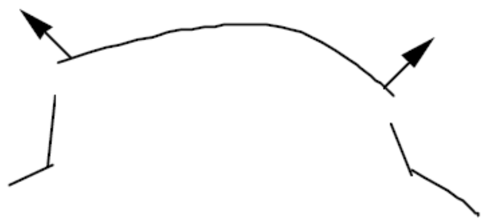

Figure 50: Springback phenomenon after extraction from the tool. (*Simtech, 2009*)

Also important to refer is that details A and C are, according to Volkswagen standards, considered as Reference Point used afterward to part measurement control. With these references, it is possible on operation 4, to use pilots to locate the part in order to cut the remaining trim areas, minimizing tolerances and consequently geometry errors.

The pilot nose picks up an existing hole and moves the stock strip or part into proper location before the stripper makes contact.

Pilot point diameters are commonly dimensioned 0.05mm smaller than the punch point diameter used to perforate the locating hole. This prevents the stock strip or part from sticking.

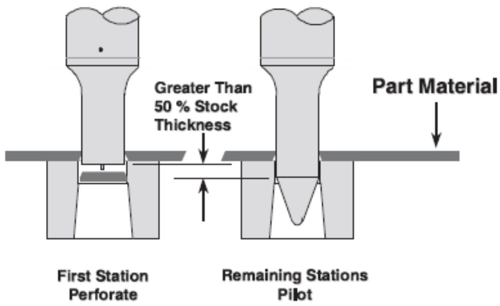

Figure 51: Piloting operation. (*Dayton Progress Corporating, 2003*)

Pilots are used to locate the part material in the stamping tool.

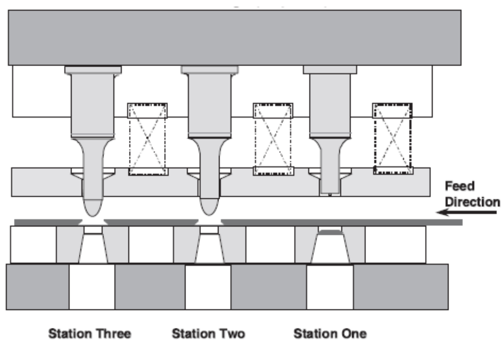

Figure 52: Location the part material in the stamping tool using Piloting. (*Dayton Progress Corporating, 2003*)

Pilots have rounded or tapered noses, allowing it to enter an existing hole without deforming the part material. Once the pilot nose starts entry, the feeder releases the part material. This allows the pilot to pull the part material into proper location.

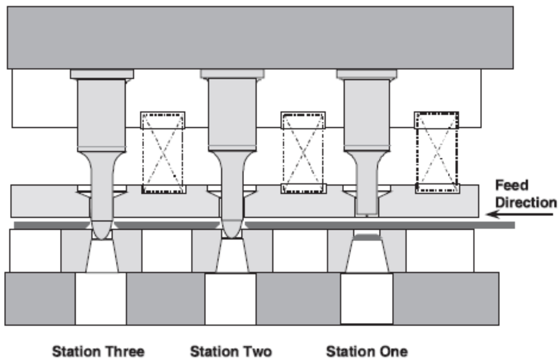

Figure 53: Feed release during a Piloting operation. (*Dayton Progress Corporating, 2003*)

The stripper makes contact, holding the part material in position. Perforating punches should be the last component to contact the part material.

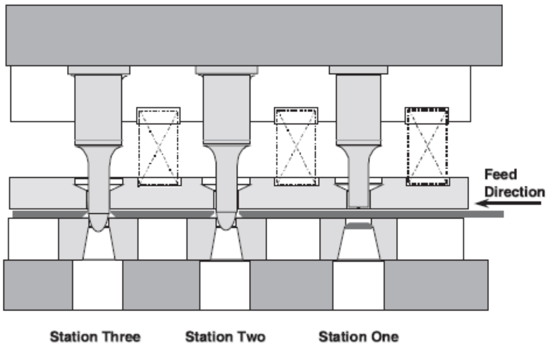

Figure 54: Stripper contact during Piloting operation. (*Dayton Progress Corporating, 2003*)

The working length of the pilots is generally 2 to 3mm longer than the perforating punches in simple die applications. The difference in length between the punches and pilots varies depending on whether it will be used shear and heal on the punches and if forming operations are being performed.

As the pilot continues through the material, it enters the matrix or the die.

Proper die clearance for pilots is subject to debate. Many designers maintain a very tight clearance of 0.01mm or less, incorporating the matrix as a guide below the part material. This offers additional lateral support those results in a better part location when forming or working with thick material.

The drawback with tight clearance around a pilot is when a misfeed causes a pilot to perforate a hole. The extreme stripping force created by the tight clearance galls the pilot, possibly pulling it from the retainer.

Another practice employed by designers is to use material thickness as the clearance per side around pilots. The intent is to allow enough room around the pilot for the part material to extrude down into the matrix without grabbing the pilot. The problem is that when the material pierces and extrudes down, it tends to spring back resulting in excessive stripping force.

Because the working length of pilots reaches beyond a fully extended stripper plate, the part material may not strip properly. To minimize this problem, must not be allowed pilots to reach more than 0.25 to 0.5 stock thicknesses beyond the fully extended stripper.

At this point with pilots locating the part, cutting knives remove the unnecessary trim areas.

After the pilots totally withdraw from the stock strip, the feeder engages the stock strip before the stripper leaves the part and feeds it to the next station.

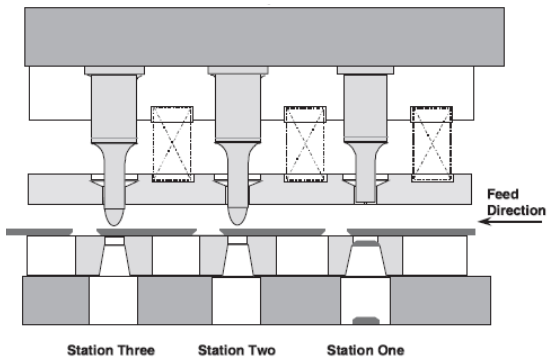

Figure 55: Feeding operation. (*Dayton Progress Corporating, 2003*)

Once the part material has been fed to the next station, the cycle repeats.

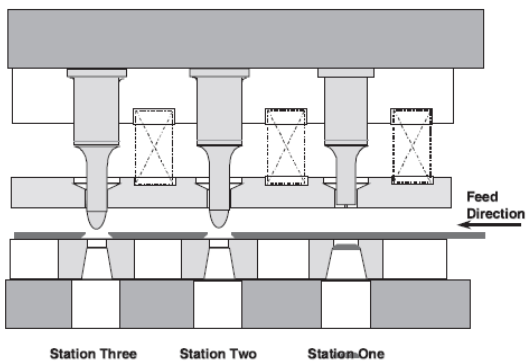

Figure 56: Open tool for a new cycle. (*Dayton Progress Corporating, 2003*)

As explained before, Figure 57 shows the remaining trim flanges removed during operation 4.

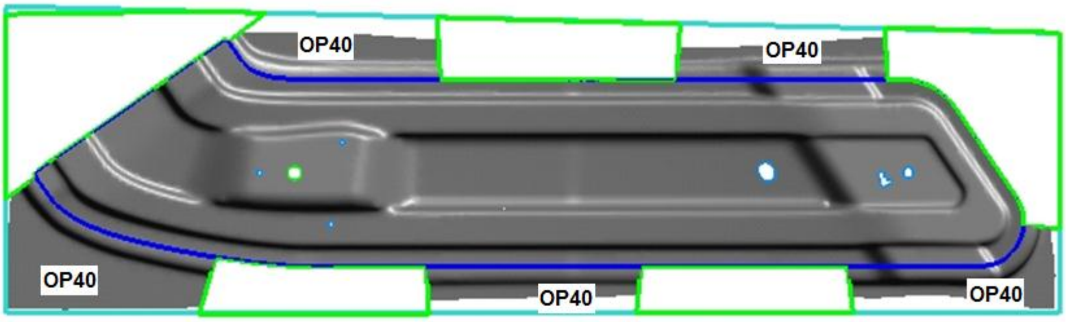

Figure 57: Operation 4. Final trim flanges are cut. (*Volkswagen Stamping Simulation Department*)

The last step, operation 5, is used as a calibration stage, where the main areas of the part are controlled and if necessary lightly corrected, mainly due to the springback effect from previous steps. Also in this case, pilots are used to locate the part in order to increase the process accuracy. This part has 3 important surfaces: flat area to weld the nut for seat belt fixation and the 2 flanges, which are contact points between the rail guide and remaining body structure.

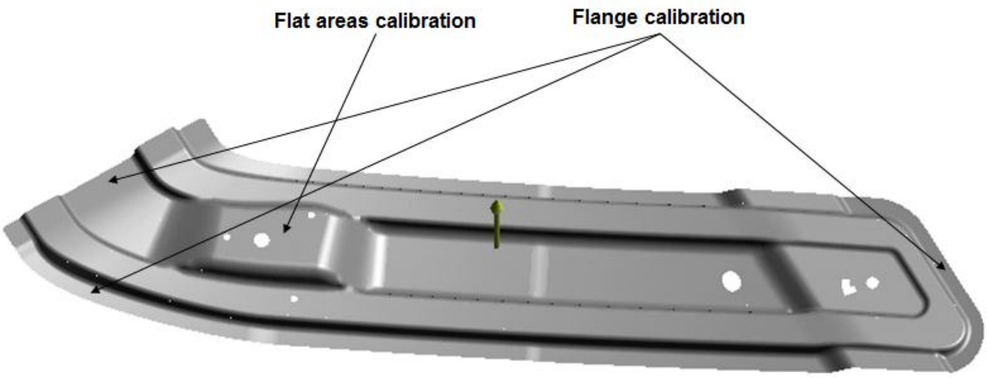

Figure 58: Operation 5: Part calibration. (*Volkswagen Stamping simulation department*)

Inverse Simulation of Sheet Metal Forming

In this kind of simulation, a die engineer has from base the final geometry of the requested part, and based on that will to set up a non-linear system, which will enable to establish the nodes position on the initial shape. The starting point of the inverse approach is the discretized model of the stamped part. The algorithms of the inverse simulation enable the user to establish the position of the mesh's nodes on the initial blank, which is considered to be plane or of known shape.

During the sheet metal forming process, a displacement field is associated to the nodes. This field is the basis of the calculation of the deformations, stresses, and internal forces, necessary for the search of the stamped blank's equilibrium, taking in account also the basic properties of the part material and also the characteristic of the press where this part will be produced. Usually an inverse simulation should not include the characteristics of the press, although and in order to save time doing an unnecessary robust non-linear problem, all the characteristics are taking in account already in the beginning of the simulation.

Taking a deepest look about the inverse simulation, it is supposed to model the blank to the product of each forming operation, analyzing its result and reconsidering some particular areas if necessary.

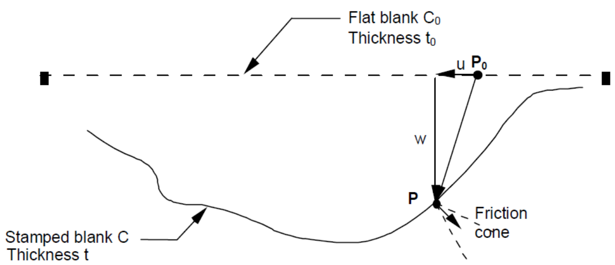

Figure 59: Inverse simulation representation. (*Simtech, 2009*)

Taking in account that as known elements in this stage are the thickness of the initial blank, the geometry, displacement w of the node P, restraining force and friction from the stamped part, the objective is to have a good production stamped part always concerning about the final thickness of the stamped part and its feaseability.

Altought this kind of simulations requires time, that nowadays is not enough when every year each brand is launching more than 10 completely new models with more than 10.000 new metal formed parts that need to be analyzed. Reagrading this detail, it is also possible to simplify all the inverse method.

To proceed in this direction, some premises must be taken:

- Regarding radial strains, the deformations are not considered and also it is possible to use the Henky-Mises integrated plasticity theory:

$$\bar{\sigma} = \frac{1}{\bar{\bar{E}}} P^{-1} \bar{\varepsilon}$$

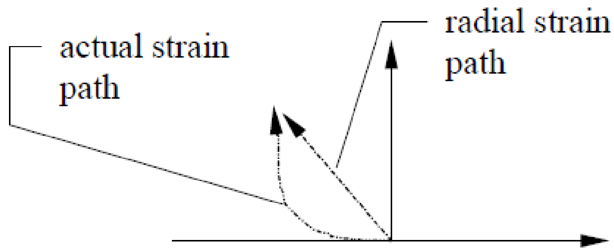

Figure 60: Inverse method simplication. (*Simtech, 2009*)

Also regarding static analysis, the contact between tools and blank are only approximately considered, due to the fact that it is not a so relevant parameter.

As all kind of simplification, also in this case, when the simulation is done with the simplified inverse method, it is possible to have an estimated error between 15 to 20% of the deformation for most parts (*Simtech, 2009*). However, it is easier and faster to recheck and even after the tool is done to correct some little details, than to assume all the main characteristics of the problem in the earlier stage of the simulation.

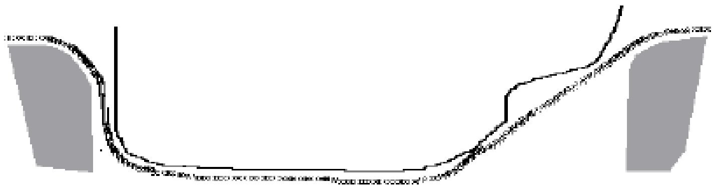

Figure 61: Simplified inverse method error. (*Simtech, 2009*)

Simulation of the stamping process of the current part using AutoForm®

The first simulation using the program Autoform®, was made for the original 2010 Sharan project, in which was possible to evaluate each step of the entire stamping process, taking in account the following aspects:

- simulating all stages: bending, stamping, cutting and calibration;

- calculated forces and stress on tool and on the part;

- analyze and improve the pieces faults, cracks, splits, strain, and quality of parts layout.

This kind of simulation is very helpful in a design phase, due to the fact that it is possible to analyze the material behavior during all the stamping process including thickness variations in percentage at different points on each operation (Figure 62).

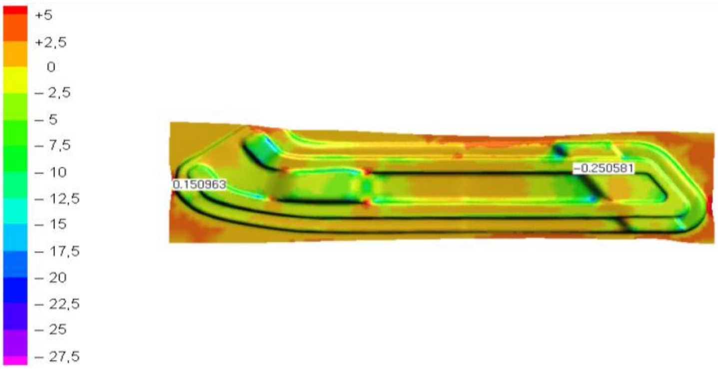

Figure 62: Part thickness deviations in %. (*Volkswagen Stamping simulation department*)

The plot starts with a yellow color, where the part has original thickness at a specific point. When the part suffers a thickness increased, the graphic shows it by red color as well as it shows blue/purple if the thickness decreases, which could give a quick visualization of where are located the most critical areas after each operation.

Taking also in mind that these kinds of parts are safety relevant items, it is also important to investigate where it is expected that the component could have thickness above the minimum requested, considering it not approved for production.

In terms of design process this analyze gives the possibility to have a quick view from the most critical stamping areas, which helps to make the project phase more profitable. Sometimes, the designed angle is not compatible with the stamping direction defined for the specific tool. With this, some areas could be more fragile and in extreme cases could also crack during the stamping process. In order to prevent those cases and also to have the best improvement as possible already in a design / virtual phase, all the parts should be intensively analyzed.

Regarding Autoform® functionality, this program is very user friendly, each means that without a great amount of information is possible to have a quick overview from all the process and main critical areas from each part. Inside the software, and in order to start a simulation, it is requested to have a CAD file from the final geometry of the part in IGES format and the respective material characteristics. Than some models could be uploaded regarding to the part geometry and complexity, for example an outer panel from a hood as a specific sample as well as underbody reinforcement has another type. At the time when this kind of simulation is done, usually it is already defined where the part will be build and in agreement with the specific plant is selected the stamping press, which will be used during normal production. This step is important, due to the fact that the user must indicate in the program which should be the press to use in the simulation. Even though all the parameters could be changed, the program has already a library with several different stamping presses in order to help the user.

Starting the analysis, Autoform® suggests an initial blank regarding the component to be simulated. Usually the suggested blank has a safety quotient associated. In this case and in order to save row material and minimize the price of the part, the user could change the geometry or the size of the blank inside the program.

Analyzing the entire simulation from the actual rail guide, Figure 63 shows the 3 main critical areas which could develop cracks in the part.

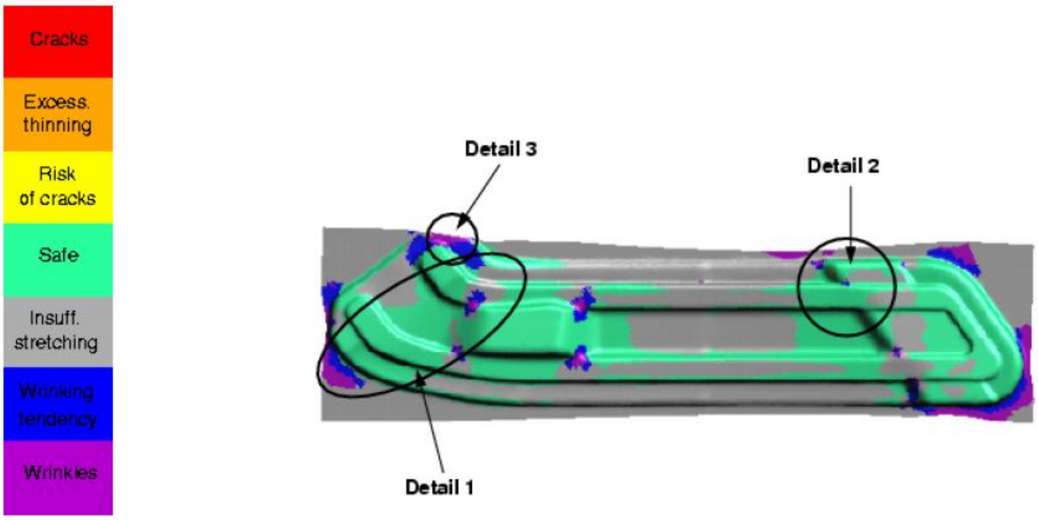

Figure 63: More critical areas regarding crack possibility in actual rail guide during stamping process. (*Volkswagen Stamping Simulation Department*)

Considering the area or Detail 1 represented in the Figure 64:

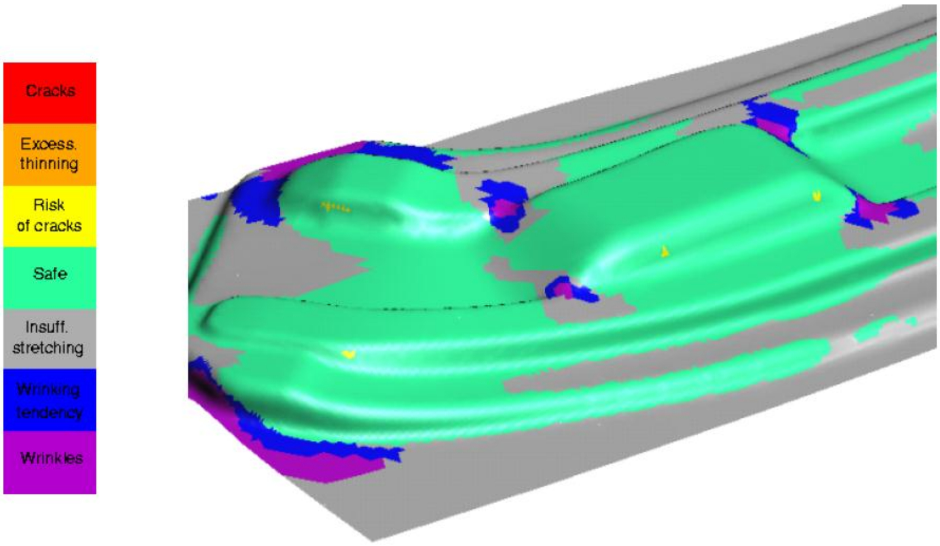

Figure 64: Risk of crack in Detail 1 area. (*Volkswagen Stamping Simulation Department*)

There was the risk of cracking on 2 radius as well as on 2 edges from lateral wall of the seat belt D-ring fixation (represented with yellow color). In order to improve this situation, the easiest and fastest way regarding radius is to increase them. Bigger radius means automatically less material extension, which represent less thickness decreasing and also smaller crack probability. Regarding lateral wall, it is important to see which angle is used inside the tool to perform the stamping operation. Surfaces with angles near 90º are harder to perform, where it is necessary to have more material flow and automatically more thickness decreasing with a risk of cracking. Considering the stamping process of the rail guide as a simple process, where there are no moving parts inside the tool to perform special angles or surfaces, the rail guide design should be keep as simpler as possible, with bigger radius, usually bigger than 4mm and surfaces with angles near 60º or less in order to stamp it without any risk of crack.

Considering the Details 2 and 3, the problems regarding radius or surface angles are the same as explained before and where it was necessary to redesign it to improve the feasibility of the part.

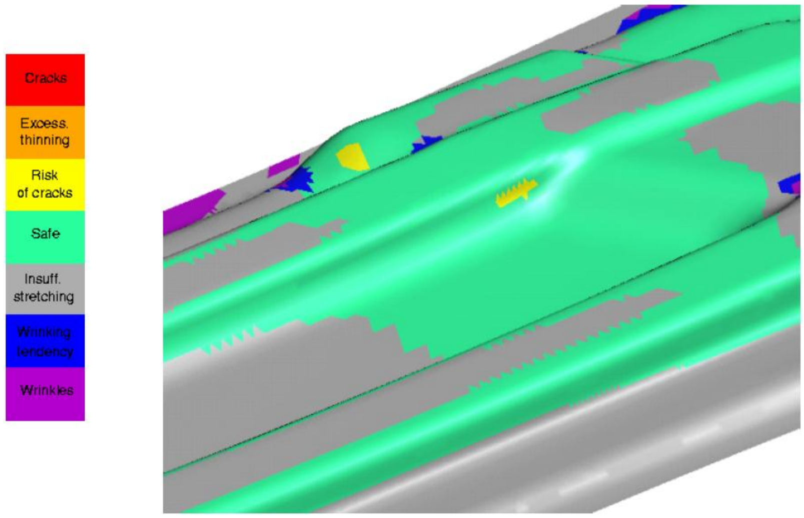

Figure 65: Risk of crack in Detail 2 area. (*Volkswagen Stamping Simulation Department*)

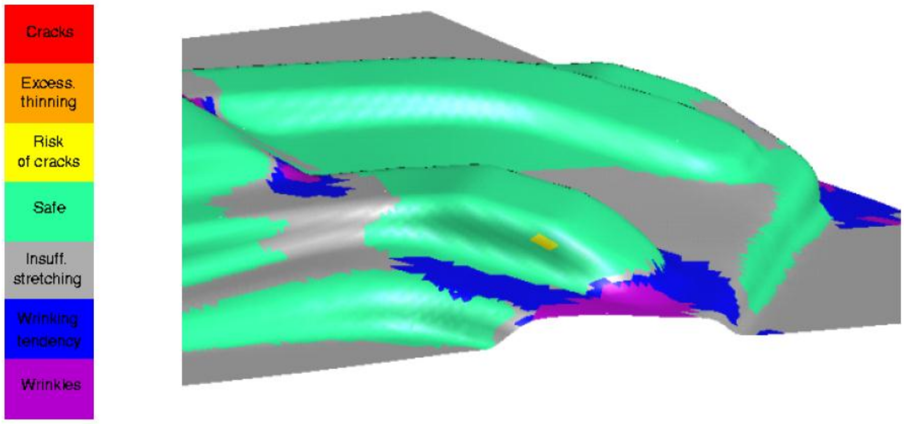

Figure 66: Risk of crack in Detail 3 area. (*Volkswagen Stamping Simulation Department*)

Also in this kind of analyzes, it is possible to visualized some other relevant problem, considering the main function of the part. In the case of outer panels or contact areas, it is very important to prevent wrinkling tendency or in the worst case wrinkles. This type of situations is not possible to rework after stamping process, which mean that the components, would be automatically scrap.

3.4 - Welding Connections in the Current Part

The part in study, is in fact a group of components and not only a single one, due to the fact that it is composed by 3 different items: guide rail, a welded speed nut and a welded stud, which are connected to the part using a projection welding technology by the supplier Gestamp Portugal.

Figure 67: Rail guide including speed nut and stud representation. (*Volkswagen AG*)

Projection welding technology is characterized by the welding current strongly localized before the weld pool is created in the top of the projection, which allows welding in an extremely large parameter range. The concentration of welding current makes projection welding more efficient than other resistance welding methods in terms of energy use.

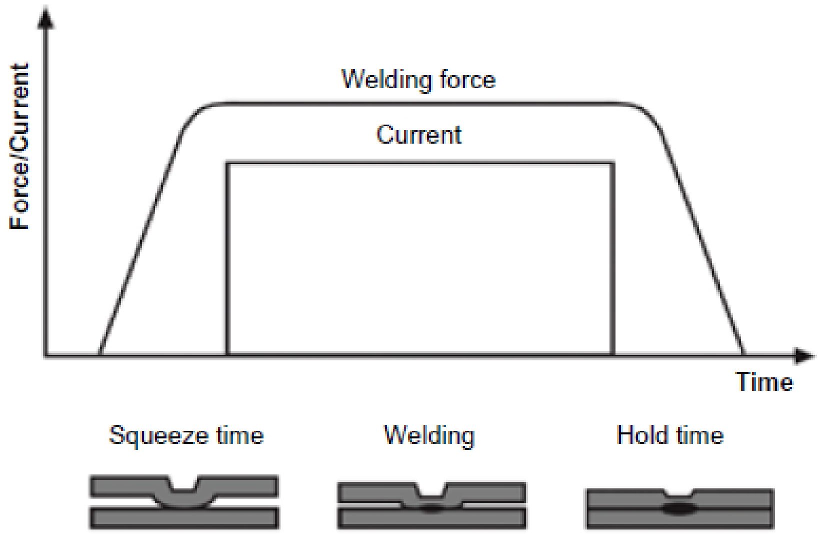

Figure 68: The principle of projection welding. (*Ruukki, 2009*)

Comparing to other welding technologies, projection welding is more efficient due to the fact that it is possible to make several welds simultaneously, which can be located relatively closer to each other without the harmful impact of stray currents. Also in this kind of technology, the contact surface between projection weld electrodes and the workpiece is large and current density small, which enables the contact surface not to be heated as in other resistance welding methods and also electrodes not to create surface damages in the metal sheet, as well as not get dirty, blunt or react with coatings.

In order to create a weld joint using projection welding, the contact surface is created between parts and the high points of the projections, when welding current is turned on, the projection and contact surface are heated and the projection collapses, which increases the contact surface and heat is created in a larger area. When the weld pool forms, the projection is already fully melted and collapsed. Post-weld hold time starts after flow of welding current through the projection is stopped. The post-weld hold time has the same function as in resistance spot welding.

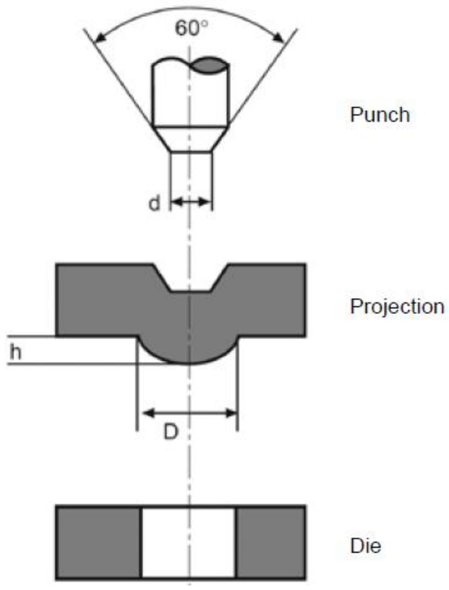

Figure 69: The making of a projection, punch and die. . (*Ruukki, 2009*)

Table 4: Dimensions used in the making of an embossed projection (*Ruukki, 2009*)

Projection diameter mm	Sheet thickness mm	h mm	D mm	d mm
2.0	0.4 – 0.5	0.5	2.0	0.63
2.5	0.5 – 0.6	0.63	2.5	0.8
3.2	0.6 – 1.0	0.8	3.2	1.0
4.0	1.0 – 1.6	1.0	4.0	1.25
5.0	1.6 – 2.5	1.25	5.0	1.6
6.3	2.5 – 3.0	1.6	6.3	2.0

As spot welding, also projection welding has some details that should be taken in mind in order to having problems during welding process. The first case is regarding the selection of correct pressing force at the beginning of the welding process, where when it is used an excessive force, this causes the projection to collapse before the weld pool is created, which increases the contact surface and reduces current density. Also variation in tensile strength of the workpiece could make the welding process harder to preform, due to the fact that it may result in projections of different sizes, in addition to which they flatten in different ways during welding.

Other aspects of projection welding

Comparing to normal spot weld, the cycle times in projection welding are slightly shorter and also pressing force must be controlled more precisely. As a consequence, the control unit of a projection welding machine must be sufficiently accurate.

Welding soft materials may be difficult if the part thickness is less than 0.50 mm, because projections may collapse before welding current is applied.

Slightly shorter weld times and greater electrode cooling power are typical of projection welding compared to spot welding.

3.5 - Welding Connection From Actual Part to Body Structure

This part has a particular influence in the rigidity structure of the vehicle.

Analyzing the entire structure from the Body of this vehicle from Figure 70, it is easy to visualize that it is not entire symmetric as well as there is no longitudinal reinforcement to the roof in the middle area. For this model the roof is a HC180Y + ZE50/50 steel part with 0.75mm of thickness and approximately 3m of length. These characteristics make the roof a fragile part especially when the vehicle has the open roof option. In this case was necessary to improve this area with one of two options: a more robust roof more resistant to torsion or a longitudinal reinforcement. Although it is also needed a seat belt to the second seat row middle seat and from all the concepts that is possible to visualized in the point 2.4 – Benchmark, was decided to develop a roof longitudinal reinforcement that could have both functions with the minimal mass and costs impact.

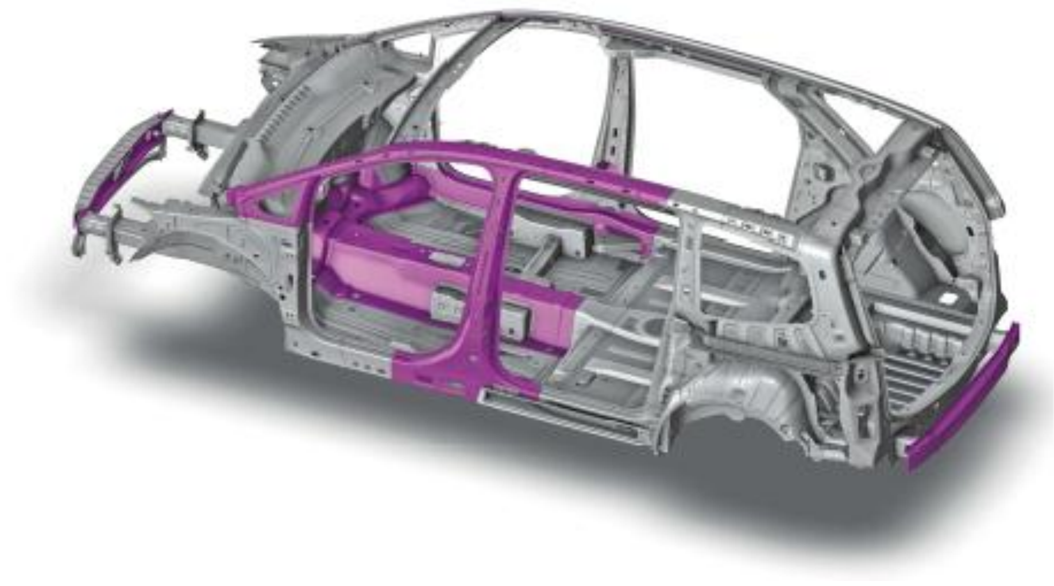

Figure 70: 2010 Volkswagen Sharan Body structure. (*Volkswagen AG*)

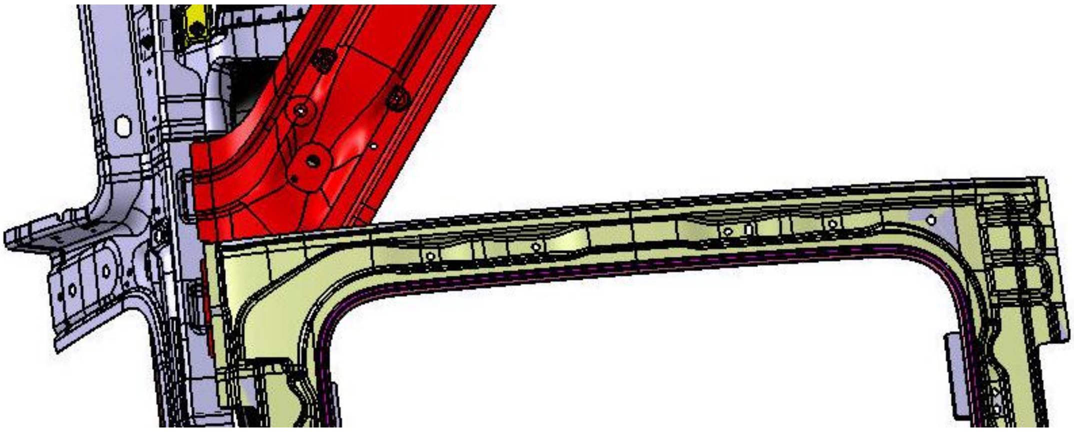

Figure 71: Support function from the Rail Guide to the open roof frame, including the D-ring seat belt fixation point.

The part in study is connected to the upper rear area of the Body welded by 11 resistance spot welds to rear roof cross member and 6 spot welds to C-pillar upper reinforcement, according to the internal Volkswagen's standards. These internal standards is experience with a high level of mechanization and from experimental results based on standards and technical regulations DVS 2902-1, DVS 2902-2 and

DVS 2902-3, integration the spot welding standards DIN EN ISO 4063 and DIN EN 10139 and also the quality standards PV 6702 and PV 6717. Figure 72, Figure 73 and Figure 74 show the part in study integrated in the Body structure as well as the weld spots that connect it to the remaining components.

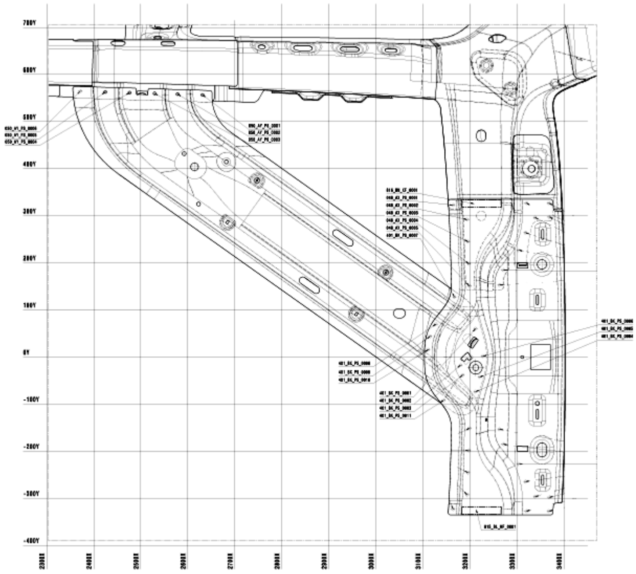

Figure 72: Rail Guide in the Body structure.

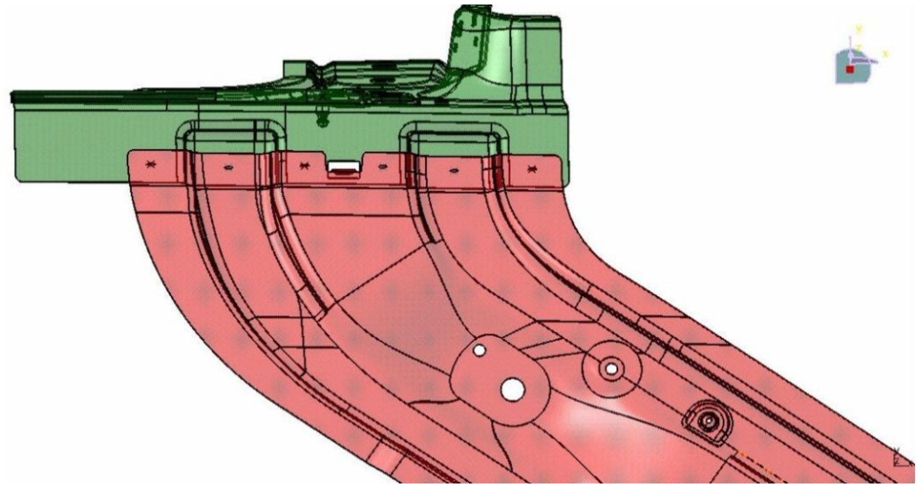

Figure 73: Connection between Rail Guide and C-pillar upper reinforcement with 6 weld spots. The components have 1mm and 1.2mm thickness respectively.

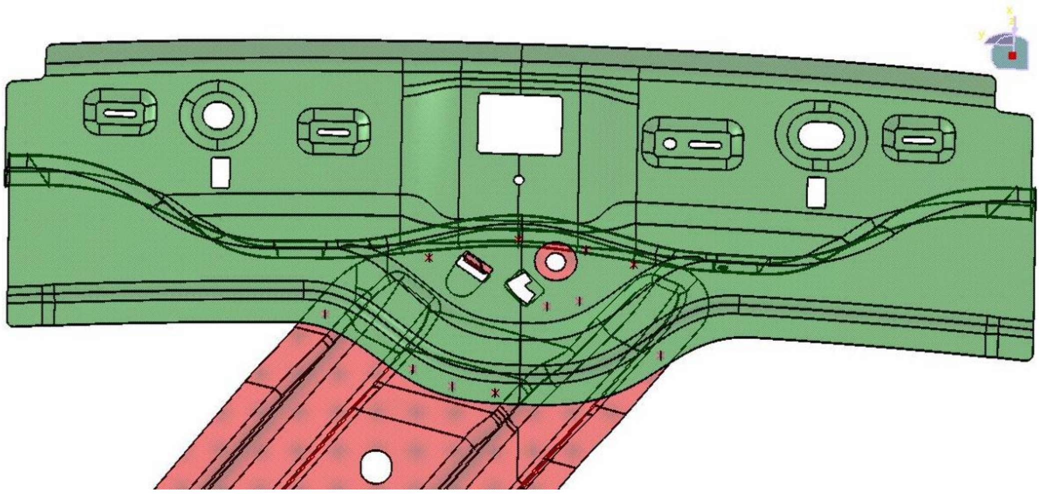

Figure 74: Connection between Rail Guide and rear roof cross member with 11 weld spots. The components have 1mm and 0.9mm thickness respectively.

This kind of technology is the most commonly resistance welding method, which is used to connect sheets together by means of lap joints, using single spot welds, which are also called nuggets. Welding current is directed to the workpieces through electrodes, which also generate pressing force. Electrodes are usually located on both sides of the component and either one or both move and transmit force to the part.

The advantages of spot welding include cost-efficiency, efficacy, good dimensional accuracy and also large-scale production possibility with a small number of employees, due to the fact that can be easily automated.

Spot welding can be used for joining several metallic materials and sheets of different thicknesses together without large deformations.

Resistance welding equipment.

The most common resistance welding machines use alternating current, AC, which has not been transformed from the supply frequency. Direct current, DC, machines have become slightly more common than before. Their welding current can be slightly lower than in AC machines.

The frame solutions for resistance welding machines can vary greatly. In larger welding units and automated production, welding force is created by means of pneumatic and hydraulic cylinders.

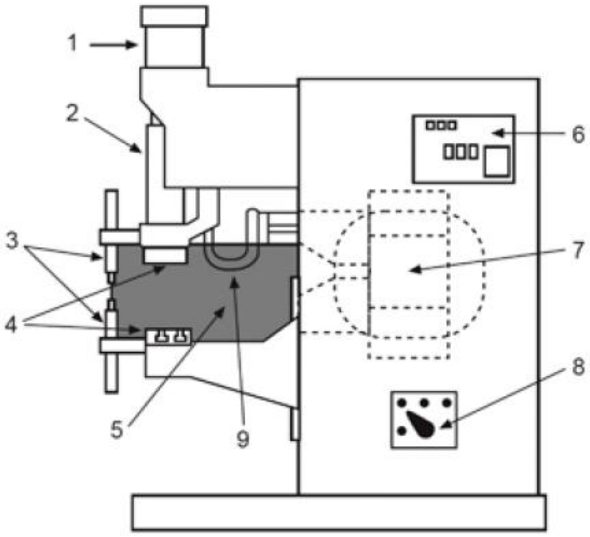

Figure 75: Ordinary spot / projection welding machine. (*Ruukki, 2009*)

Where,

1 - Pneumatic/hydraulic cylinder
2 - Push bar
3 - Electrodes and electrode holders
4 - T-plates for projection welding electrodes
5 - Throat area
6 - Control unit
7 - Transformer
8 - Transformation ratio selector
9 - Flexible conductor

The properties of resistance welding machine affect the selected welding parameters. Most resistance welding machines are powered by AC, in which case the welding current used depends on the size of the workpiece and gap surface of the welding machine. Figure 76 shows different kinds of transformers, which location also have an impact on the selected welding current.

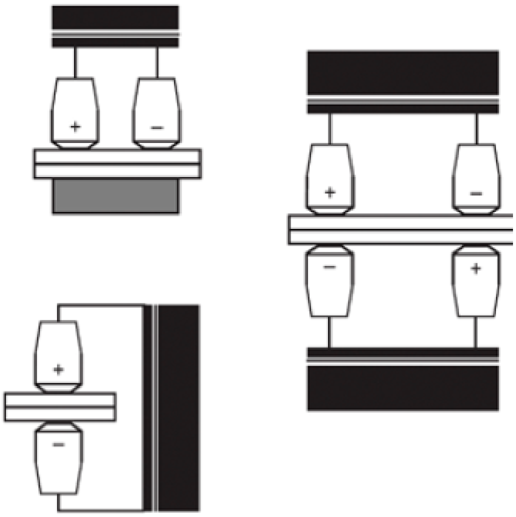

Figure 76: Different kinds of transformer solutions used in resistance welding. (*Ruukki, 2009*)

Regarding welding current, for this kind of application and in order to make one single weld, it is used a current of 4 to 20 kA, which depends on the material where it will be applied and its thickness.

Stages of resistance spot welding

The stages of resistance spot welding are: electrodes press the welded metal sheets together; electrode force decreases the transfer resistance of parts between the electrodes, which allows directing welding current through the workpieces through the desired route.

Welding current is connected after the termination of the squeeze time. It produces heat at the faying surfaces and thus creates a weld pool between the parts. Current is switched off as the weld time ends. Electrode force still presses the workpieces together and electrodes cool the weld down, which must solidify and achieve sufficient strength properties during the post-weld hold time. After the end of the hold time, electrodes are retracted from the metal sheets and the total weld time required for the production of one spot weld ends.

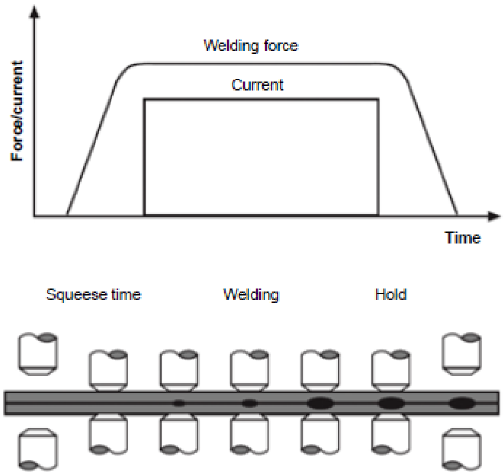

Figure 77: The principle of spot welding. (*Ruukki, 2009*)

Growth of weld nugget

The following images represent the standard nomenclature for each area of a weld nut as well as a real section from a weld produced by Volkswagen.

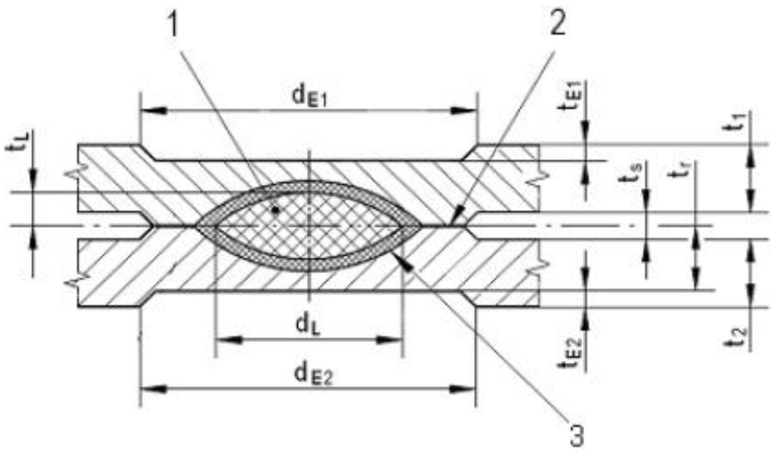

Figure 78: Spot weld. (*VW 01105-1*)

Where:

1 - Weld nugget
2 – Diffusion joint area

3 – Heat affected zone
d_{E1}, d_{E2} – Depression diameter
d_L – Nugget size
t_L – Nugget penetration
t_S – Gap between sheets
t_{E1}, t_{E2} - Indentation
t_1, t_2 – Material thickness
t_r – Minimal residual thickness in the electrode depression

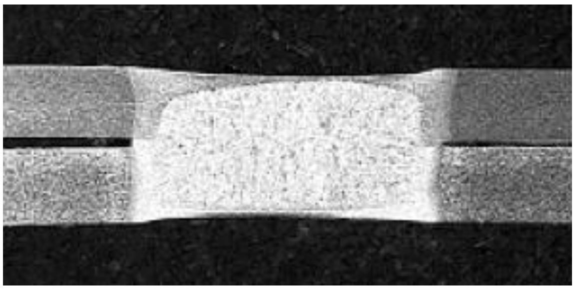

Figure 79: Spot weld section. (*VW 01105-1*)

A good spot weld has sufficient diameter and nugget penetration in order to bear the calculated loads.

The four stages of weld nugget formation and growth:

1. Heat increase, when the weld pool has not yet been created. Electrode force and the elevated temperature smooth the surface roughness of the part and transfer resistance decreases.

The amount of heat generated in an electrically conductive workpiece depends on three factors: amount of electric current, resistance of the metal sheets and the period of time of the current passing through the component. The amount of heat can be calculated using the three factors on the basis of the following equation:

$$Q = I^2.R.t$$

Where,

Q = heat generated, joules

I = current, amperes
R = total resistance of the workpiece, ohms
t = total duration of heat input (weld time), seconds

A part of the heat generated is used for melting the metal i.e. the creation of the weld, and another part is conducted to the surrounding workpiece and electrodes.

Heat input in resistance welding is controlled by adjusting welding current and weld time. The component has its own specific resistance and thermal conductivity coefficients which depend on the material and cannot thus be adjusted.

2. Rapid growth of weld nugget diameter. The weld pool is created and the molten metal diameter and nugget penetration increase rapidly. The resistance of molten metal is higher than that of solid metal, which increases total resistance.

3. The growth of the weld nugget slows down. The weld size growth slows down significantly. The growth of the weld pool is restricted by cooling electrodes and the increasing surface area of the weld pool.

4. Splash. The weld pool size increases so much that electrode tips can no longer contain the molten metal between the sheets, and therefore expulsions occur, splashing a significant amount of molten metal.

Mechanical properties of spot welds

The tensile strength of spot weld depends on the nugget diameter, nugget penetration, thickness and strength of the parts, electrode indentation and possible defects and brittleness of the weld.

The shear strength of a single spot weld can be calculated as follows:

$$\tau = 2.6 * t * d * Rm$$

Where:

τ = shear strength, N
t = sheet thickness, mm
d = weld diameter, mm
Rm = tensile strength of the material, MPa

Table 5: Welding parameters for cold rolled and coated sheets. (*Ruukki, 2009*)

Sheet thickness t, mm	Weld diameter D, mm	Electrode tip Ø d, mm	Force F, kN	Weld time cycles	Effective welding current I, kA	Minimum distance between welds, mm	Minimum acceptable overlapping between sheets, mm
0.6	4	5	1.4 – 1.7	5 – 8	6	20	12
0.8	4	5	1.6 -2.3	6 – 10	7	20	12
0.9	5	6	1.7 – 2.5	8 – 11	8	25	24
1.0	5	6	2.1 – 2.9	9 – 12	9	25	24
1.2	5	6	2.5 – 3.4	10 – 13	9.5	35	25
1.5	6	7	3.3 – 4.3	12 – 16	10	35	26
2.0	6	7	3.9 – 5.4	16 – 20	11	40	28
2.5	7	8	5.4 – 7.0	22 – 26	12.5	45	20
3.0	7	8	6.3 – 8.5	24 - 30	14	50	22

Electrodes indent at least slightly on the workpiece surface. A moderate indentation ensures that the weld is tight, but too much indentation decreases the thickness of the part on the edge weld in such a way that the strength of the weld is impaired.

Indentation must be less than 20 % of metal sheet thickness, preferably less than 10 %. Too great an indentation is caused by excessive electrode force, long weld time and inadequate heat balance where heat is created, in particular, in the contact surface of the electrodes and part.

Flanging and depressions

According to the standard VW 01105-1, there is also an important aspect to taking in account that is the minimum distance from the spot weld to a flange or a depression. As shown on Table 6, for every sheet thickness there are minimum acceptance distances from the spot welds to the border of the flange or to a depression, in order to consider it acceptable. The Figure 80 shows the functional distances for a spot weld in a flange area.

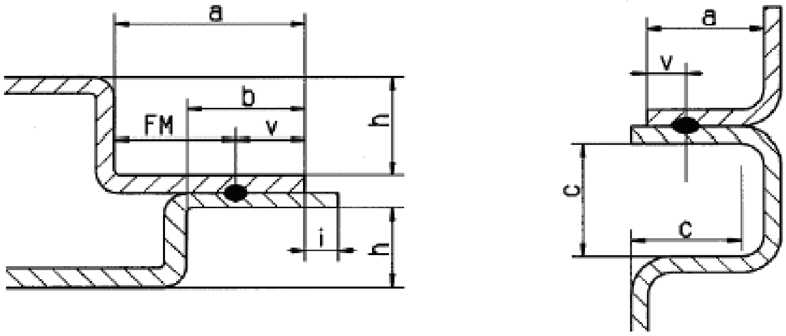

Figure 80: Functional distances from a spot weld to the border of a flange or depression. (*VW 01105-1*)

Table 6: Flange geometry and spot weld application regarding part thickness. (*VW 01105-1*)

Workpiece thickness	Flange				Diameter		Free dimension	Flange lenght
t_{min}	v_{min}	b_{min}	i	g_{max}	d_K	d_S	FM	a
0.5 to 0.6	3.3	6.6	$1.0_{-1.0}$	1.1	2	13	13	8.5
> 0.6 to 0.8	3.9	7.8	$1.0_{-1.0}$	1.3		16	18	11
> 0.8 to 1.0	4.3	8.6	$1.5_{-1.5}$	1.5				
> 1.0 to 1.2	4.8	9.6	$1.5_{-1.5}$	1.7				
> 1.2 to 1.5	5.3	10.6	$1.5_{-1.5}$	2.0				
> 1.5 to 1.6	5.6	11.2	$2.0_{-2.0}$	2.5				
> 1.6 to 2.0	6.3	12.6	$2.0_{-2.0}$	2.5		20	20	12
> 2.0 to 2.5	6.8	13.6	$2.0_{-2.0}$	3.0				
> 2.5 to 3.0	7.6	15.2	$2.0_{-2.0}$	3.5		24		14
> 3.0 to 3.5	8.1	16.2	$2.5_{-2.5}$	4.7				
> 3.5 to 4.0	8.8	17.5	$2.5_{-2.5}$	4.7				

Testing and quality management of spot welds

It is difficult to visually inspect the size and mechanical properties of spot welds. The easiest way to inspect size is to break the joint and measure the diameter of the weld. A simple and much used destructive testing method is the peel test, where consecutive welds are made to two metal sheet slit strips, after which the sheets are torn apart.

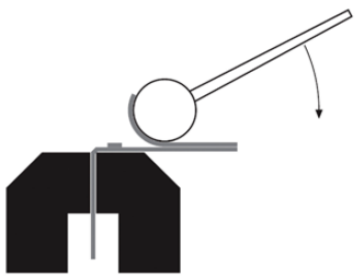

Figure 81: Peel-test. (*Ruukki, 2009*)

The weld diameter is measured as described above. The peel test can be used to define the weldability range and ideal welding parameters of a material. The peel test is easy to carry out in a production environment and no specific machinery is needed. The test must, however, be complemented with destructive tests of the end products in order to take the part geometry and size into account in the welding process. Brittleness and mechanical properties of the weld can also be deduced from the fracture surface of the opened welds. Simple destructive tests can also be complemented with tensile tests to assess the tensile strength of the welds. Specific specimens made of sheets are used in tensile testing. Tensile test require specific machinery.

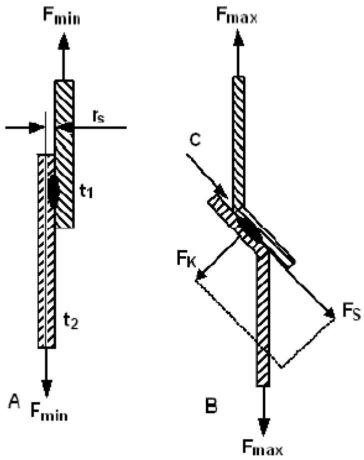

Figure 82: Shear test. (*VW 01105-1*)

Where:

A – Prior to the tensile

B – After the tensile test (exaggerated)

C – Outer groove

F_k – Cross tension (% from F_{max})

F_S – Shear (% from F_{max})

For this situation and according to the standard PV 6702, for a radical proof should be used the following equation:

$$F_{Smin} = F_{max} - 2s$$

Where,

S – Standard deviation

F_{max} – Average of the maximum force (DIN EN ISO 14273)

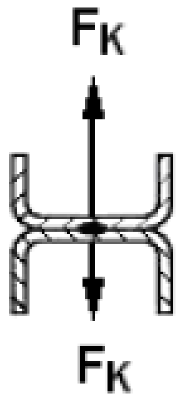

Figure 83: Cross tension. (*VW 01105-1*)

Where, according to DIN EN 10130:

$$F_K \leq 0.6 F_{min}$$

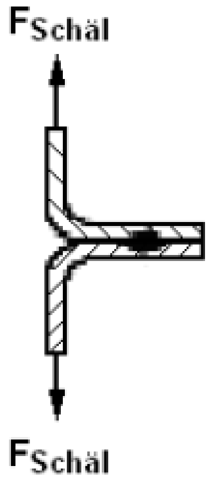

Figure 84: Peel tension. (*VW 01105-1*)

In this case and according to DVS 2902-3:

$$F_{Schäl} \leq 0.2F_{min}$$

Weld diameters can also be measured using nondestructive testing. Such tests are usually carried out by means of ultrasound equipment, which could also be used to assess some defects in the weld; however it does not fully replace destructive testing.

It is recommended to carry out routine testing in production in order to control the quality of products. In this case, visual testing and the peel test are sufficient. Inspections must be carried out daily during each shift, whenever electrodes are maintained or welding parameters adjusted and immediately after changing the welded material or maintaining the welding equipment. Testing and inspection should be made on end products whenever possible.

4

Current Part Modeling and Testing

Abstract: In this chapter, the current part modeling is presented, including the virtual and physical tests necessary to approve it for production. It is also described why and where are the most critical areas from the rail guide in terms of stress, as well as, the nature of the load that the part is submitted during a vehicle frontal impact.

4.1 - Introduction

The development of the current component involves 2 phases, design and testing. In the design phase, Finite Element analysis was used to guide the design and access a feasible solution. For this solution prototype were built and submitted to experimental tests, required by the passenger safety regulations.

4.2 - The ECE R14

To guarantee proper function of the seat belt system, belt fixing points have to resist to a defined static test loads that represent a vehicle frontal impact, with minimal damages. The document ECE R14 is the Economic Commission for Europe Technical Report R14, which specific the requested test to ensure sufficient strength of all anchorage points. In these test high loads are slowly applied and sustained over a long

This chapter is largely based on internal Volkswagen AG information, including Volkswagen Forschung und Entwinklung and Volkswagen Wettberwerbanalyse.

period of time to the seat belts using loading devices, which makes possible analyze of this system as a quasi-static test.

The correct model and simulation process of the complex load application system is essential for significant and accurate computational results.

As said before, ECE R14 is a test to ensure the strength of the seats, the seat belts and the fixing point. Therefore, test loads are applied by loading devices, so called body blocks, and transferred by the seat belts to the vehicle structure.

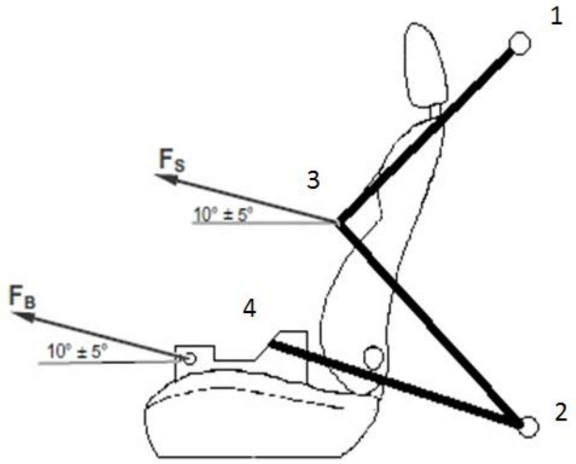

Figure 85: Sketch of the load application on the seat belt according to ECE R14.

Although there are some specifications regarding which system is being tested. In the case of this project, it is supposed to test a configuration of a three-point belt without retractor or with a retractor at the upper belt fixation in a N1 category (Vehicle under 3.5ton from Table 7), due to the fact that the retractor is located on the rear area of the vehicle after the upper belt anchorage.

Table 7: ECE R14 test loads according to vehicle's mass in tons. (*ECE R14*)

	Classification		
	N1: m < 3.5ton	N2: 3.5 < m< 12ton	N3: m > 12ton
Shoulder block	13.5 kN	6.75 kN	4.5 kN
Lap Block	13.5 kN	6.75 kN	4.5 kN

A test load of 13.5 kN with a tolerance of ± 0.20 kN shall be applied to a traction device attached to the both opposite fixing points, upper and lower from the same belt, using, if supplied by the manufacturer, a retractor fixed at the upper belt anchorage. At the same time a tractive force of 13.5 kN ± 0.20 kN shall be applied to a traction device attached to the lower belt fixations. Both forces represent the inertia moment from the passenger to the seat belt during a vehicle frontal impact.

Analysing the test in detail, it is composed by 2 body block: lap block and shoulder body block.

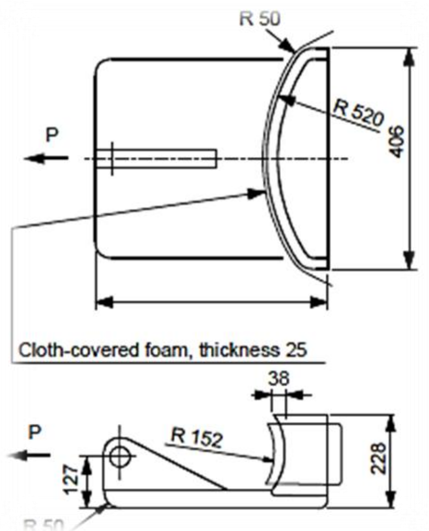

Figure 86: Lap block from an ECE R14 test. (*ECE R14*)

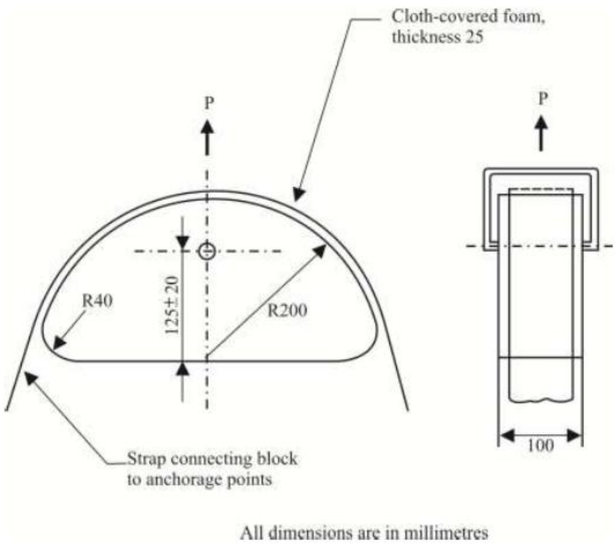

Figure 87: Shoulder body block from an ECE R14 test. (*ECE R14*)

According to ECE R14, the lap block present on Figure 86 is placed onto the seat cushion and then, when possible, pushed back while the belt strap is pulled tight around it. The shoulder body block, Figure 87, is placed in position, the belt strap is fitted over the device and pulled tight. No preload beyond the minimum necessary for correct positioning of the test device shall be introduced to safety-belt fixations during this operation.

There are also some other premises in order to perform this kind of test:

- The positioning of the traction device shall avoid any mutual influences during the pull test which adversely affects the load and its distribution.
- Because the loading devices are not tied to the seat belt or the seats, contact and slipping between all parts can occur. Therefore these components build a complex kinematic system and the configuration under load determines the distribution of the applied loads to the fixing points. Hence a correct modeling of the kinematics is essential for significant and accurate computational results.
- All the belt fixations from the same group of seats shall be tested simultaneously. However, if there is a risk that non-symmetrical loading of the

seats and/or anchorages may lead to failures, an additional test may be carried out with non-symmetrical loading.

- The traction force shall be applied in a direction corresponding to the seating position at an angle of 10° ± 5° above the horizontal in a plane parallel to the median longitudinal plane of the vehicle.
- A preload of 10% with a tolerance of ± 30% of the target load shall be applied; the load shall be increased to 100% of the relevant target load.
- Full application of the load shall be achieved as rapidly as possible, and within a maximum load application time of 60 seconds. The belt anchorages must withstand the specified load for not less than 0.2 second.

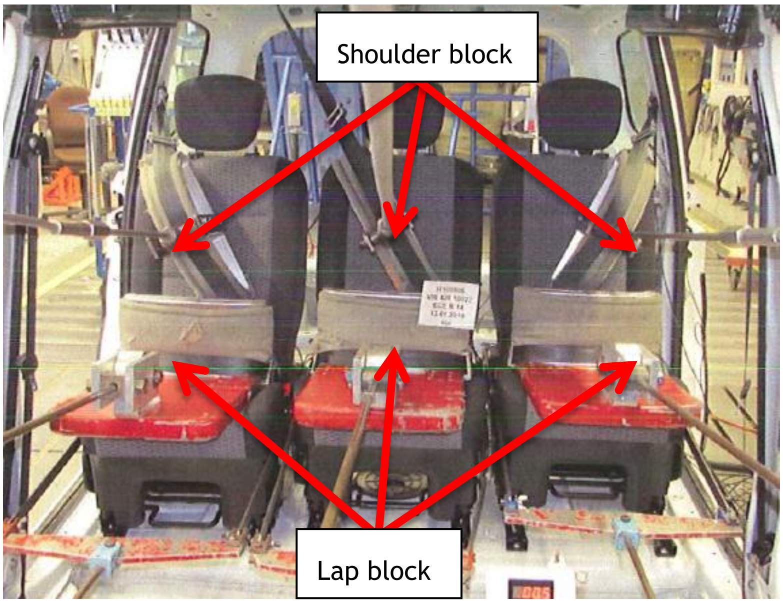

Figure 88: Volkswagen Sharan ECE R14 test for the second row seats. (*Volkswagen Simulation Department*)

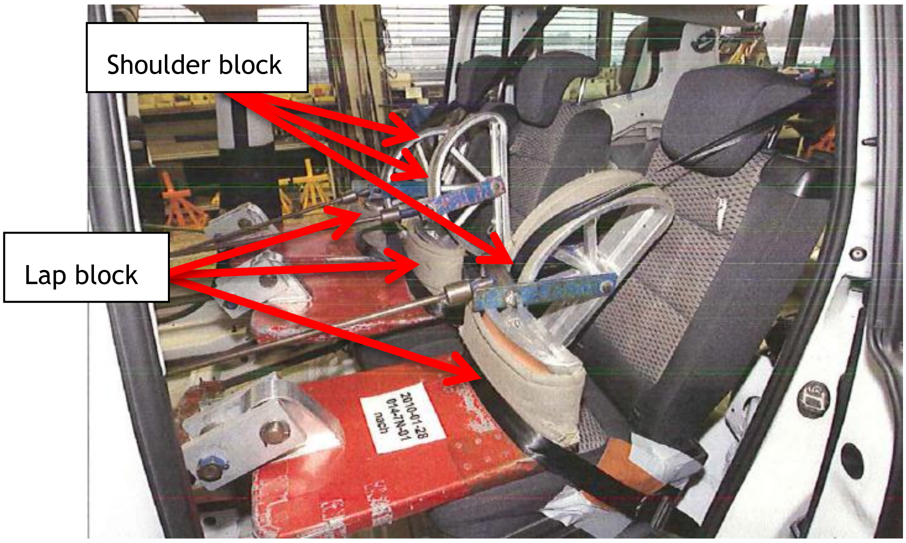

Figure 89: Volkswagen Sharan ECE R14 test for the second row seats. (*Volkswagen Simulation Department*)

4.3 - Virtual Major Deformations

Finite element models of vehicles have been increasingly used in preliminary design analysis, component design and vehicle crashworthiness evaluation. These simulation models are becoming more sophisticated over the years in terms of their accuracy, robustness, fidelity and size. The need for developing multipurpose models that can be used to address safety issues for a wide class of impact scenarios becomes more apparent.

Complete body vehicle models are used to perform vehicle impact simulation, Figure 90, however the results of this kind of analysis are less feasible than detailed models, where fine messes are developed in order to give more accurate results.

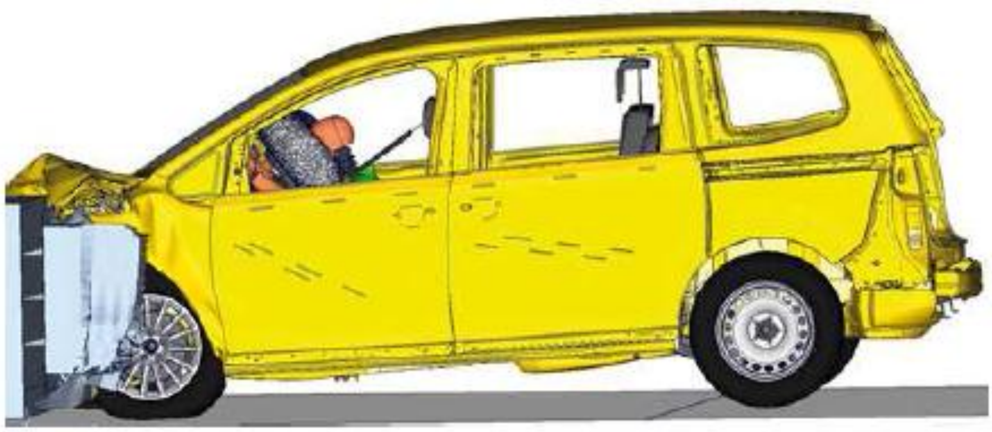

Figure 90: Complete Vehicle frontal impact simulation. (*Volkswagen Simulation Department*)

A detailed multi-proposed finite element model of the rail guide analyzed in this study was developed specifically to address vehicle safety issues, mainly regarding frontal impact of a 2010 Vokswagen Sharan. The current component mechanical resistance was evaluated in the design phase, by performing the simulation of ECE R14 test. For reasons of computational costs, only part of the vehicle body is considered in this simulation.

In Figure 91, it is possible to visualized that was only modeled in detail the guide rail section, including the component and connection parts where it is welded, C-pillar and rear cross member, due to the fact that for this specific study, it was only necessary to understand the behavior of those specific parts and not the behavior of the entire vehicle. Important to refer that in this case all the involved part are deformable, in order to guarantee the maximum feasibility of this model according to real results.

In order to avoid unreal movements, the evolving part of the rail guide will be analyzed as hyperstatic, the results from the virtual test could be worst as reality.

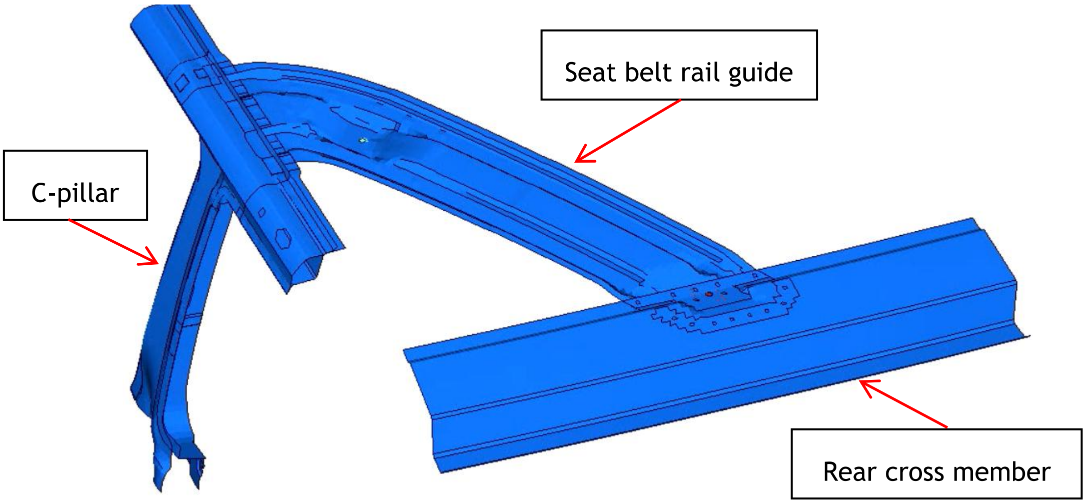

Figure 91: Reduced model, contemplating only the guide rail and the other parts where it is connected.

The Finite Element model, or FE model, is developed using the real dimensions of each part, where a three dimensional geometric data of each component previous designed in Catia® and translated to IGES format.

The simulation was performed on the commercial program PAM-CRASH® including the SAFE EDITOR module. This software is a package from ESI Group used for crash simulation, which enables automotive engineers to simulate the performance of a proposed vehicle design. PAM-CRASH® works through a pre-meshed model gave by the user and simulate a requested impact situation with dedicated crash test simulation solutions. For this study, it should be choose a frontal impact standard evaluation in order to check the feasibility of the seat belt rail guide.

The first step in order to perform the simulation should be the mesh definition for the parts, which is made using the pre-process mesh generator software ANSA®, where is possible to select different kind of meshes depending on how accurate results are requested. This software is a computer aided engineering tool for finite elements analysis in automotive industry, developed by BETA CAE Systems S.A. ANSA® maintains the association between CAD geometry and the FE mesh, which makes easy to maintain and update any change in the geometry by simply reworking the updated area instead of recreating the FE from scratch.

Both programs were used for this study, due to the fact that they are the official licensed simulation software inside Volkswagen Group to perform finite element evaluations.

Starting ANSA® software, Figure 92, it is necessary as a first step to load the parts in study. It was decided to load separately each part in order to mesh them also separately. The implementation done for the first part would be used in the same form for the other components. After this process, would be implemented all the contact conditions between them.

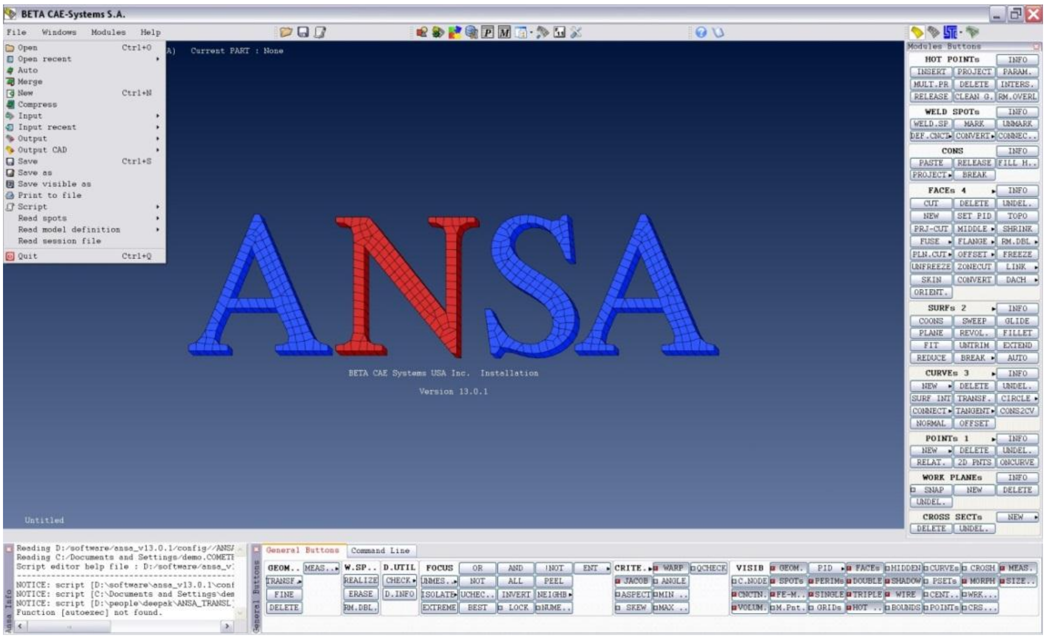

Figure 92: ANSA® starting menu.

After loading the part, it is necessary to associate its material characteristics, Figure 93.

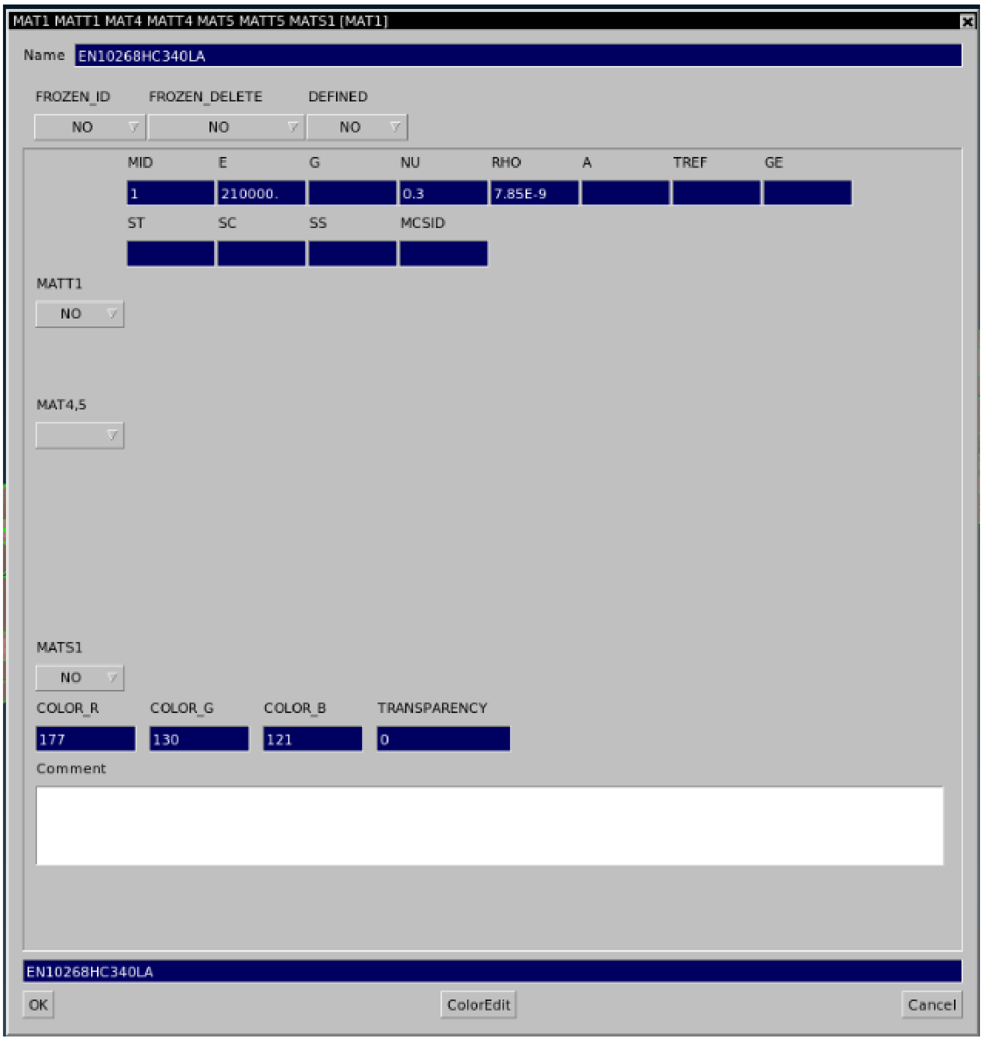

Figure 93: Material definition in ANSA®.

In this case, the rail guide material was the first one to be implemented showing the MID, Material identification, as number 1. In this case was introduced the main relevant characteristics of the HC340LA as Young's modulus E=210000Pa, Poisson's ratio NU=0.3 and mass density RHO=7.85e-9Kg/m^3.

After material input and correct association to the part, it is possible to proceed to mesh definition.

In ANSA® it is possible to choose between beam structure and shell structure elements for mesh definition, according to the type of analysis that is requested, as shown on Figure 94.

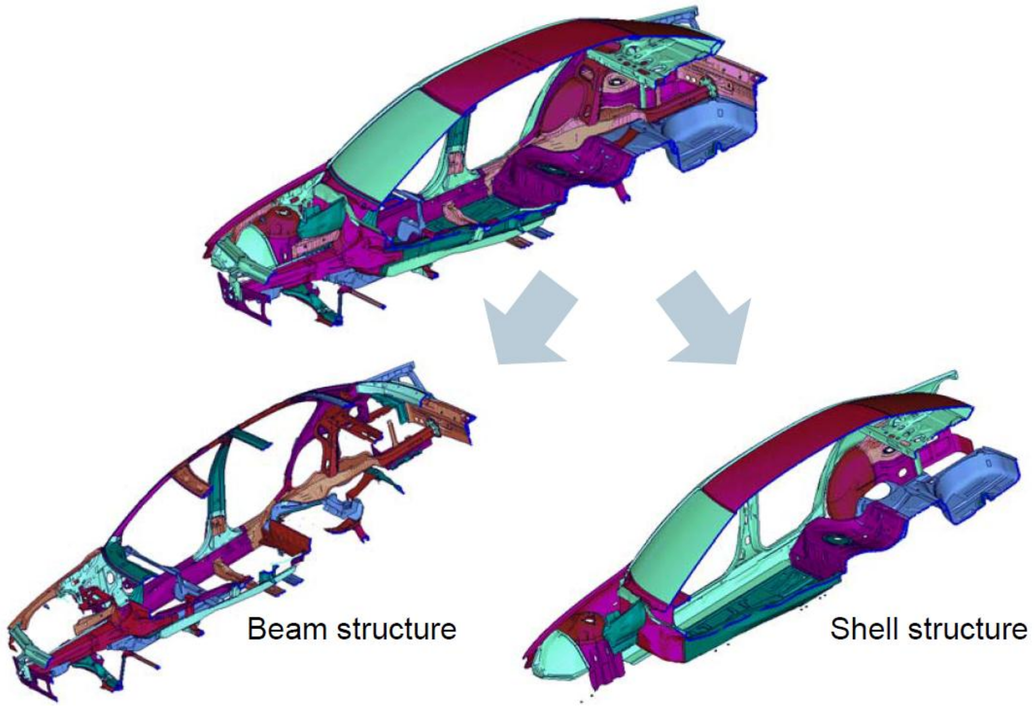

Figure 94: Different element types possible to choose inside ANSA® software. (*BETA CAE Systems S.A.)*

Considering the characteristics of the part in study, where its thickness is much smaller than the other 2 directions, the best option is to choose shell elements.

Selecting shell structure, ANSA® meshes de component automatically with a mix of QUAD4 and TRIA3 elements, where are defined as 4-node quadratic and 3-node triangular elements. In this step, the user must define the requested element length for the application. Usually for global simulations, for example complete body vehicle frontal impact analysis, the element should be defined with 8mm length. In case of local analysis, like the component in this study, the element should be defined between 2 and 5mm according to the requested accuracy of results. In this project was used a 5mm element. In Figure 95, is showing an example of mesh definition from element 10473 from the rail guide, with shell QUAD4 element type.

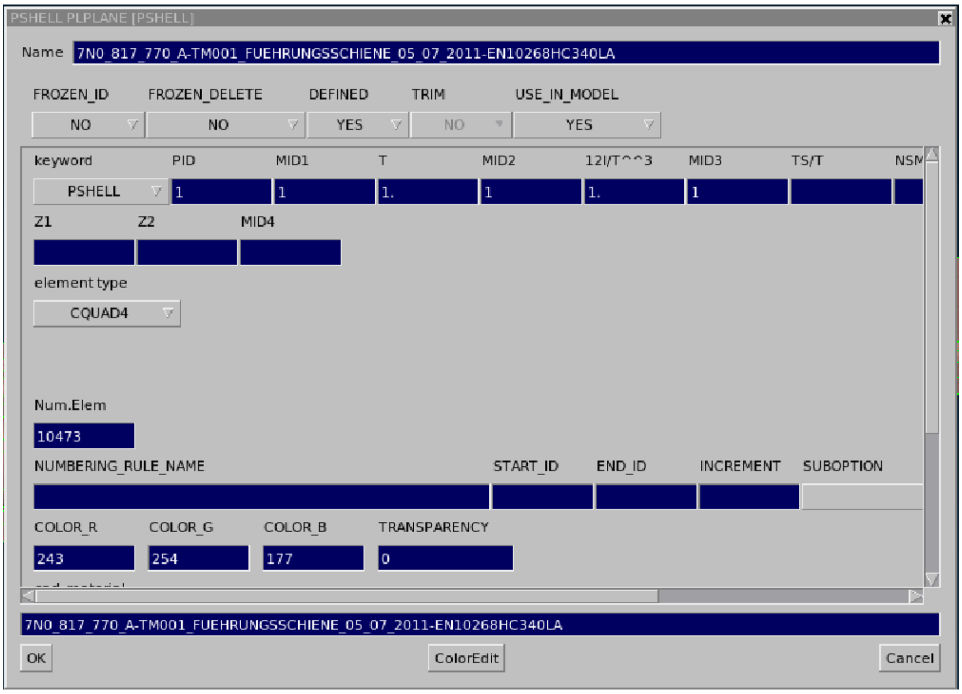

Figure 95: Example of shell element definition in ANSA®.

Analog to the process described before, it would be necessary to define the materials and properties for the other components present on this detailed model, which involves basically three steel materials: the guide rail made by HC340LA, the C-pillar upper reinforcement by HX340LAD+Z100MB and the rear roof cross member by TL 1550.

Table 8: Detailed model components characteristics regarding material and thickness.

Component	Material	Young's modulus, Pa	Poisson's ratio	Mass density, Kg/m^3	Thickness, mm
Rail guide	HC340LA	210000	0.3	7.85e-9	1
C-pillar reinforcement	HX340LAD+Z100MB	210000	0.3	7.85e-9	1.2
Rear cross member	TL 1550	210000	0.3	7.85e-9	0.9

These kinds of components have a fairly linear stress-strain relationship at low strain values, but at higher strains the material yields and the response becomes non-linear and irreversible.

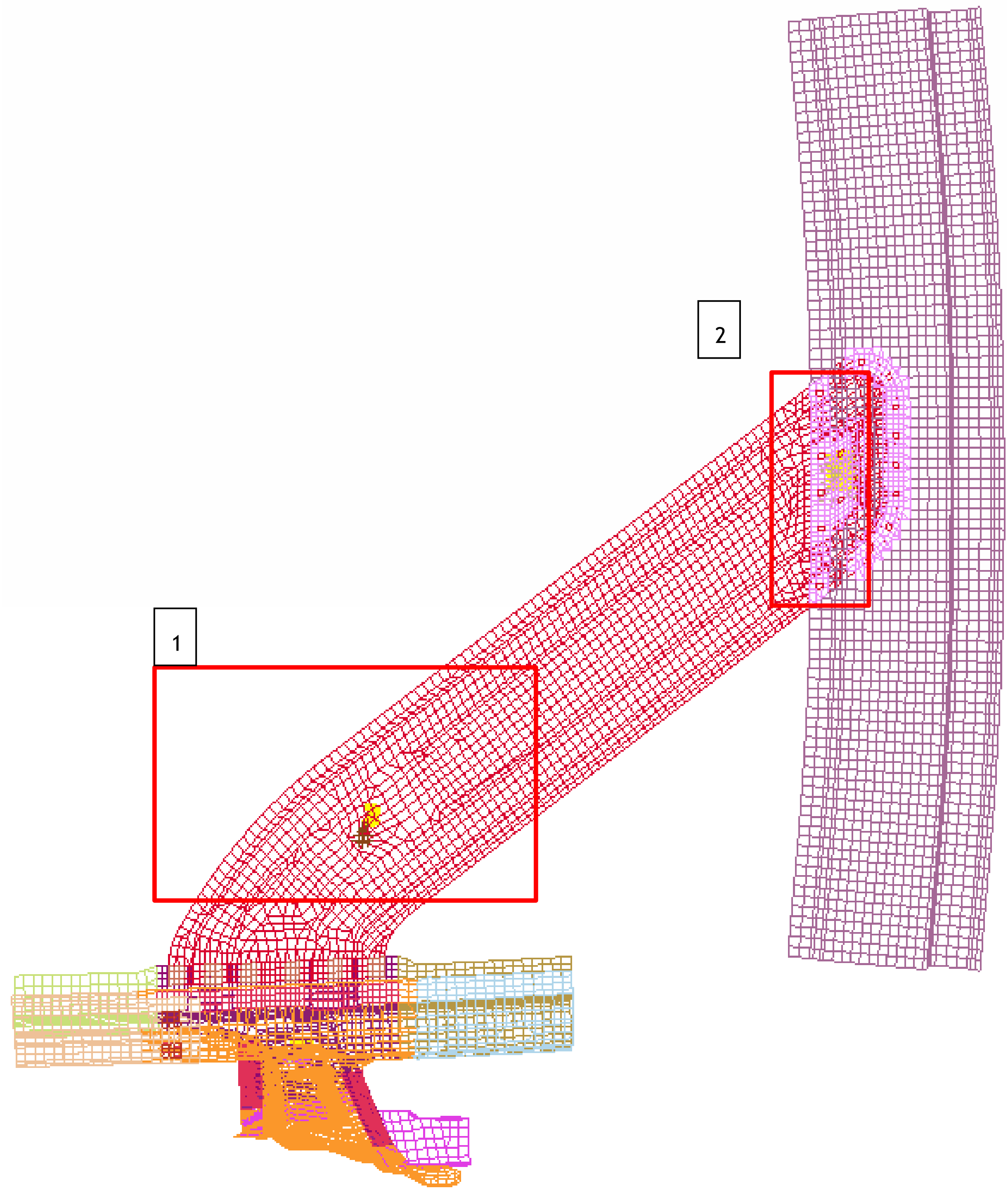

Figure 96: Mesh model modeled using ANSA® application.

According to a detailed analysis from Figure 96, it is possible to identify 2 critical areas where the mesh shows distorted elements. Figure 97 and Figure 98 represent respectively the details 1 and 2 from Figure 96. Due to the complexity of the geometry in specific areas, some approximations and geometry clean-up had to be done to have a more homogeneous mesh from the model.

Despite of the fact that a fine mesh with a lot of elements gives more accurate results than a rough one, it was necessary to mesh the rail guide in a rough way. This is because holes, fillets and other design features within the geometry of the component in study rapidly increase the number of elements needed and, as a result, the computational cost of the analysis and the stability of the model are affected. These approximations in the part had been therefore done considering that meshing process is time consuming and keeping in mind that it's mesh has to give a satisfying accuracy when testing the final model.

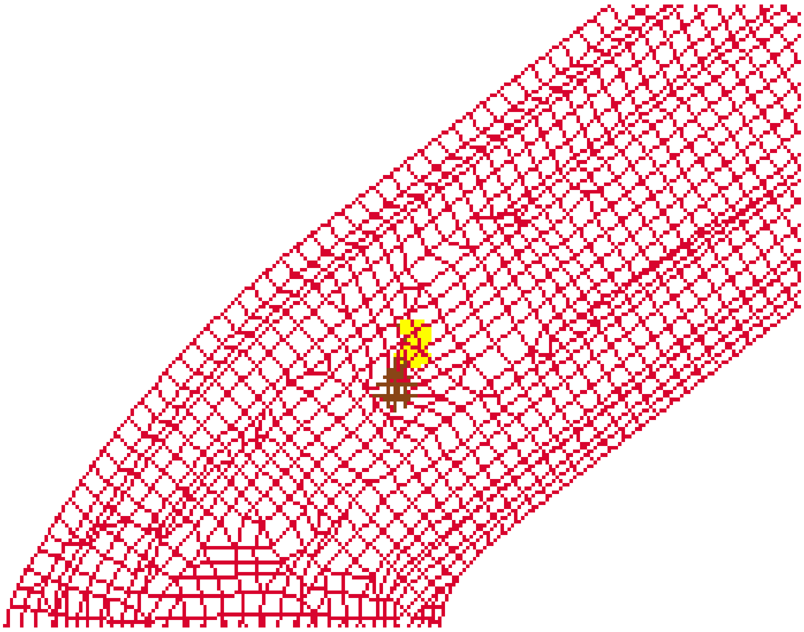

Figure 97: Detailed representation from the mesh in D-ring fixation point.

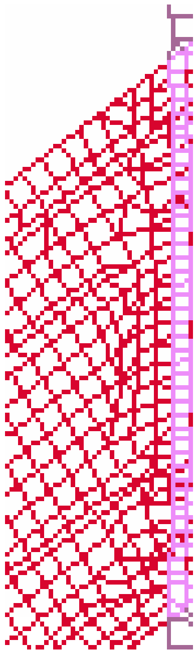

Figure 98: Detailed representation from critical area 2 on Figure 96.

Finishing the mesh generation to the detailed model, it is necessary to analyze its behavior under the requested environment. As said before, the program used by Volkswagen Group to this kind of simulations is the PAM-Crash®.

Inside PAM-Crash®, and opening the previous model, it is necessary to start to input the relations between all the components. In this case there would be defined 2 contact areas, first between rail guide and C-pillar and second between rail guide and rear cross member. In order to proceed with this implementation, the user must indicate de contact nodes between them. In this case was considered simple global contact for all the metal-metal surfaces, with a friction coefficient of 0,45 between rail guide and C-pillar, due to the fact that this last component has a coated zinc surface and 0,5 between the part in study and rear cross member.

In this case the contact type is defined as 2-ways master-slave surface to surface, which would request to indicate which component is the master and which is the slave. However and due to the fact that in this study there is no rigid body in analyze and both parts could be deformed, it was choose a 2-way type of contact, which allows for compression loads to be transferred between the slave nodes and the master segments as well as from the master nodes for penetration through the slave segments. In other words, the treatment is symmetric and the definition of the slave surface and master surface is arbitrary since the results will be the same. Tangential loads are also transmitted if relative sliding occurs when contact friction is active.

In the next procedure, it is necessary to define the boundary conditions for each part, which are applied to avoid the motion of some parts of the model. Only 2 components of the model, rear cross member and C-pillar reinforcement, are constrained in order to avoid its translation movement in all the directions; however there are rotation degrees of freedom in these areas.

Due to the fact that in this study is only considered a reduced model from the entire vehicle, encastre boundary conditions must be implemented in the same way to all the borders from C-pillar upper reinforcement and rear roof cross member, in order to simulate a fixation from these 2 components to the body structure.

In Figure 99, blue color are marked all the encastred nodes, which have $U_1 = U_2 = U_3 = 0$ according to the global referential. This represents the translation constraint in these areas.

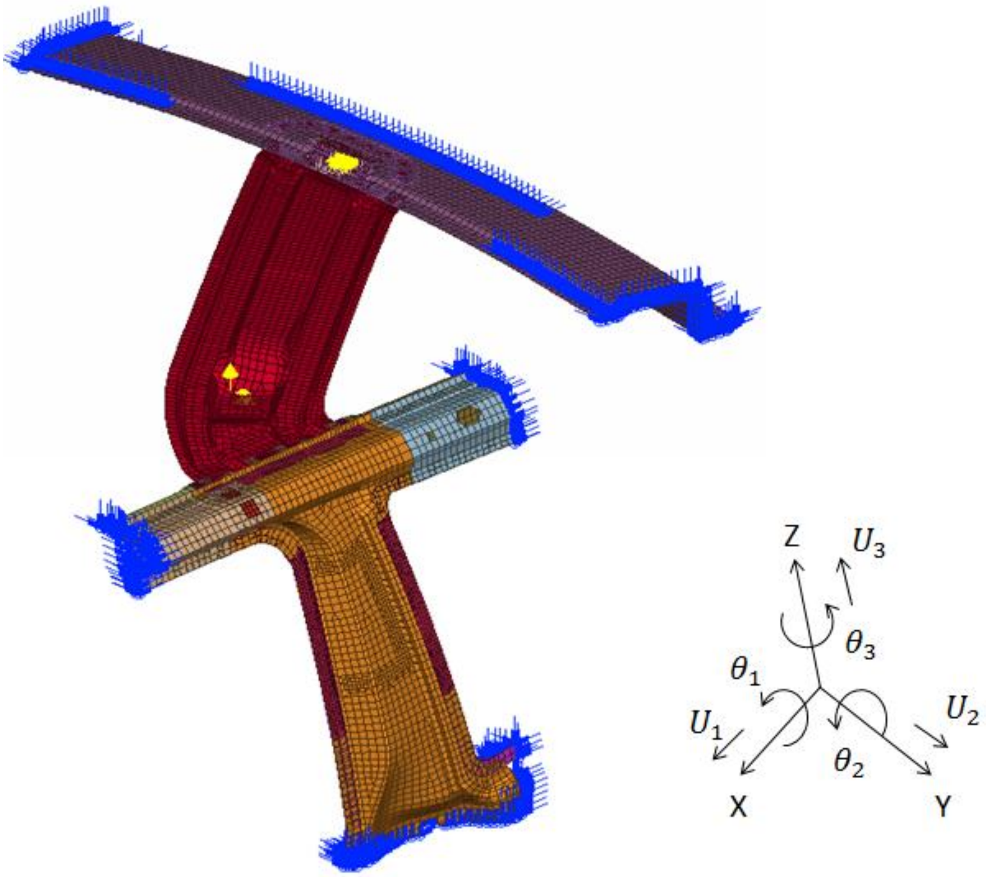

Figure 99: Boundary conditions definition.

Also regarding boundary conditions, and even after considering the contacts between parts, they are not only contacting to each other but also welded to each other. The spot welds, or in PAM-CRASH® language Plinks, must be introduced, due to the fact that the parts are physically connected in those specific areas.

Plinks are implemented in PAM-CRASH® using the “Spot weld and Rivet” model, which ties two or three nodes with a joint of finite strength. While this joint is unbroken the nodes behave as a rigid body.

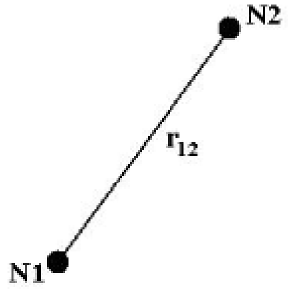

Figure 100: Nodal constraint spot weld option. (*S.M. Molenaar, 2009*)

From the forces acting upon both nodes of the spot weld model, i.e. the external minus the internal contributions the interaction force f_t can be calculated by:

$$f_1 = f_{1e} - f_{1i}$$

$$f_2 = f_{2e} - f_{2i}$$

$$f_t = \frac{f_1 - f_2}{2}$$

This interaction spot weld force is decomposed in a normal (N) and a shear (S) component in the following way:

$$f_N = (f_t . r_{12}) r_{12}$$

$$f_S = f_t - f_N$$

The term r_{12} is the position vector from node N1 to node N2. The norms of the two component forces frame the rupture criterion of the spot weld.

Also possible to perform is the "General Interface Spot weld", which uses a special type of interface contact, *type 42*. This contact type connects two independent meshes by either a spot weld connection or a rivet connection, depending on the choice of the input parameters.

During initialization, an automatic search algorithm finds from these two groups a master segment and a slave segment from both connected part. For both of these found segments, the distance to the geometrical position of the spot weld location is minimal. After this procedure, a normal projection of the spot weld on each of the segment is performed, Figure 101.

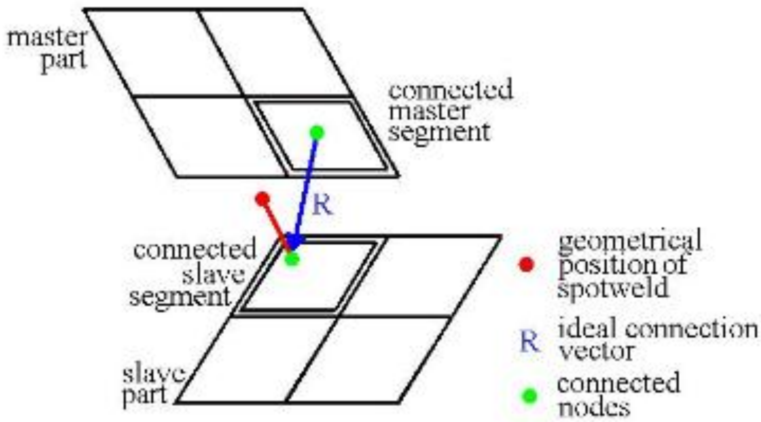

Figure 101: Spot weld location and connected nodes. (*S.M. Molenaar, 2009*)

At the local coordinates of this normal projection nodes are generated on both the master and slave segments. The nodes are called "connected nodes", which will always remain at their positions defined by the local coordinates. The procedure to find these nodes is iterative.

To decide whether the model must describe a spot weld or a rivet, the parameter *I3DOF* is used as a flag. This flag decide whether the rotational degrees of freedom of the vector between the two connected nodes must be penalized or not. If all the 6 degrees of freedom are penalized (*I3DOF=0*), both the rotational and translational variations of vector R with respect to the initial configuration are corrected by penalty moments and forces respectively. This situation implies a physical spot weld model, presented in Figure 102.

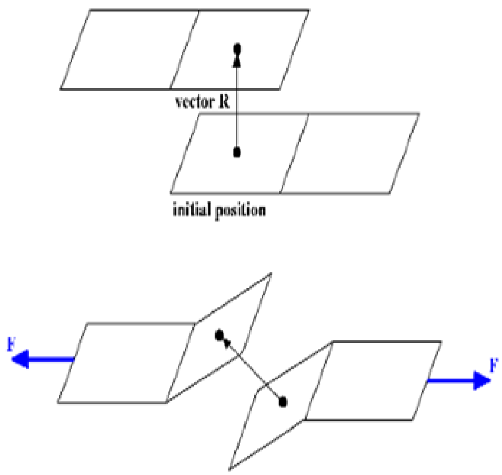

Figure 102: Spot weld model. (*S.M. Molenaar, 2009*)

This model is specially used in order to perform durability test.

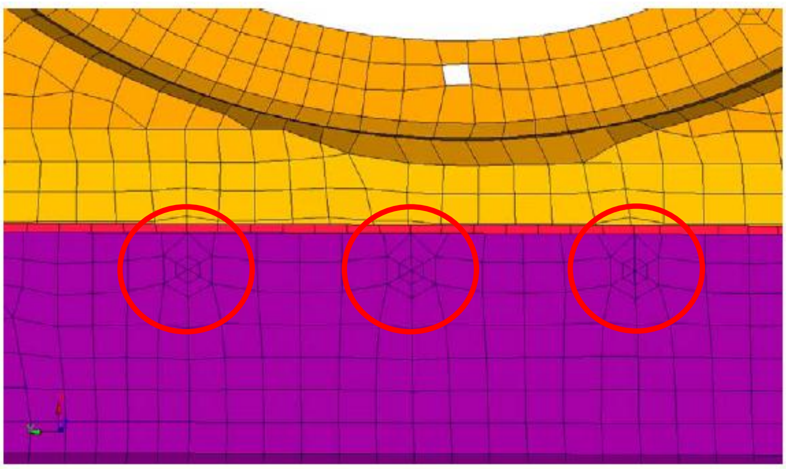

Figure 103: "General Interface Spot weld" implementation in PAM-CRASH®. (*BETA CAE Systems S.A.)*

In this study, it was supposed to perform a crash simulation, which let to choose the first option, where it is applied a rigid body in order to perform the spot weld.

Both models described before will fail according to a specific failure model, the rupture criterion model, which differs slightly from the universal rupture model, and could be described by:

$$\left(\frac{|f_N|}{A}\right)^2 + \left(\frac{|f_S|}{B}\right)^2 \geq 1$$

In this equation the parameters A and B represent the maximum normal and shear forces respectively if just one type of loading is applied on the spot weld. Failure is initiated from the time when the above failure criterion is first violated. Once the rupture criterion is surpassed, the nodal constraint gradually ceases to exist over a period of 20 time steps, or within a user specified failure time interval.

After assigned the boundary conditions, it is necessary to implement the loads that are applied to each component.

According to Figure 85 and also to the standard ECE R14, the torso from a human body suffer during a frontal impact, a load F_S = 13.5 kN on a N1 category vehicle with an angle in Z of 10º ± 5º.

Due to the fact that the seat has free movement in X direction and this analysis should be developed taking in account passengers with different weights and different torso's perimeter, the simulated load must be analyzed as a 3D load with Z direction.

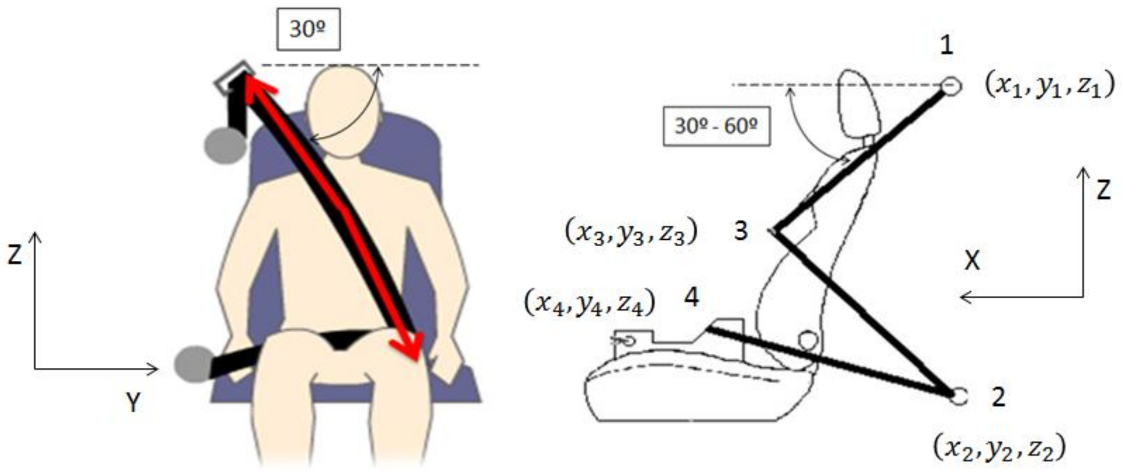

Figure 104: $\boldsymbol{F_S}$ load components applied to rail guide

Analyzing the fixations and contact point from Figure 85, it is possible to assume that are applied 3 loads to point 3, represented in Figure 105, in which an applied load on the seat belt has the same direction from the seat belt:

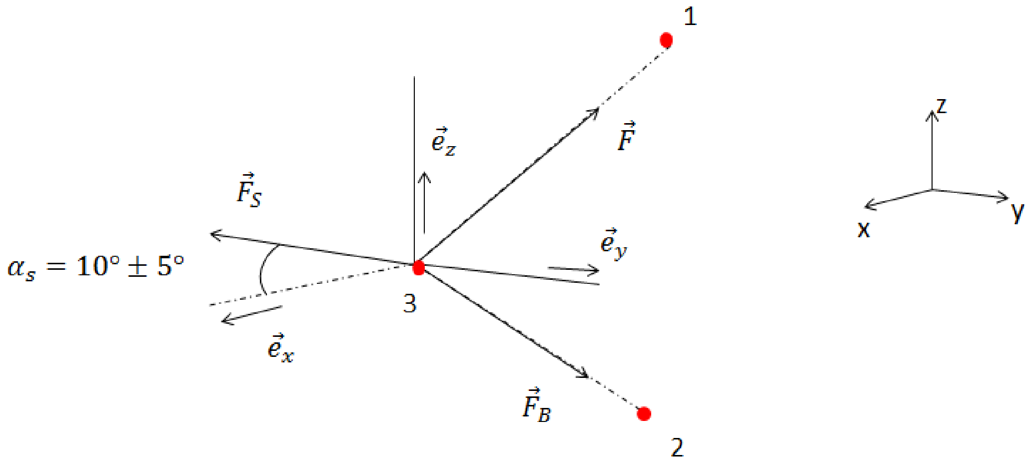

Figure 105: Loads representation on Figure 85 point 3.

With $\|\overrightarrow{F_S}\| = \|\overrightarrow{F_B}\| = 13{,}5 \pm 0{,}2\ kN$.

Figure 106 represents the loads applied to fixation point number 2:

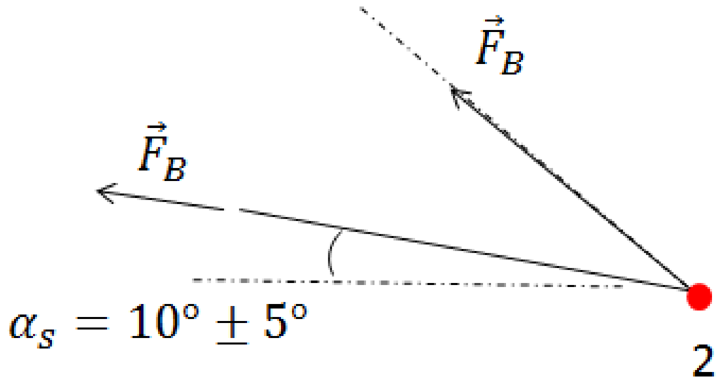

Figure 106: Loads representation on Figure 85 point 2.

Analyzing the previous figures it is possible to conclude that:

$$\overrightarrow{F_S} = F_S \cos\alpha_S \overrightarrow{e_x} + F_S \sin\alpha_S \overrightarrow{e_z}$$

$$\overrightarrow{F_B} = \frac{\overrightarrow{r_{32}}}{\|\overrightarrow{r_{32}}\|} F_B = \frac{(x_2 - x_3)F_B\overrightarrow{e_x} + (y_2 - y_3)F_B\overrightarrow{e_y} + (z_2 - z_3)F_B\overrightarrow{e_z}}{\sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2}}$$

Considering previous equations, it is possible to assume that $\vec{F}$ from Figure 105 is:

$$\vec{F} = \overrightarrow{F_S} + \overrightarrow{F_B} \Rightarrow \begin{aligned} F_x &= F_{Sx} + F_{Bx} \\ F_y &= F_{Sy} + F_{By} \\ F_z &= F_{Sz} + F_{Bz} \end{aligned}$$

For this simulation must be choose the worth case considering the variations from $\alpha_s \epsilon [5°, 15°]$ and the position (x_3, y_3, z_3).

Analyzing directly to the component in study, it is possible to assume that $\|\vec{F}\|$ keeps the same value in every section of the rail guide.

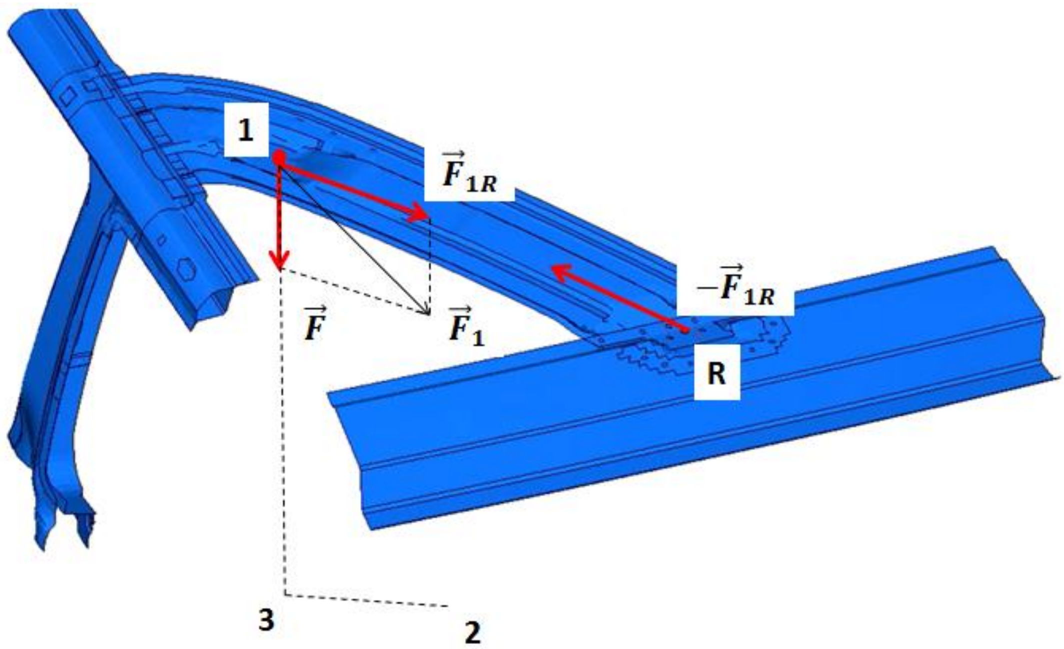

Figure 107: Loads applied to the guide rail.

During a front impact and due to the fact that Volkswagen Sharan is equipped with automatic seat belt, this means that also the retractor positioned on the rear cross member will apply a load between 8kN and 10kN depending also from the volume of the passenger and how strong is the impact. In the point R, where is positioned the retractor, the applied force is:

$$-\overrightarrow{F_{1R}} = \frac{(x_R - x_1)F\overrightarrow{e_x} + (x_R - x_2)F\overrightarrow{e_y} + (x_R - x_3)F\overrightarrow{e_z}}{\sqrt{(x_R - x_3)^2 + (y_R - y_3)^2 + (z_R - z_3)^2}}$$

With the previous consideration, it is possible to define the total load applied to the D-ring fixation in the guide rail, point 1 in Figure 107:

$$\overrightarrow{F_1} = \vec{F} + \overrightarrow{F_{1R}}$$

$$\begin{aligned}\overrightarrow{F_1} = {} & (F_S \cos\alpha_S \, \overrightarrow{e_x} + F_S \sin\alpha_S \, \overrightarrow{e_z}) \\ & + \left(\frac{(x_2 - x_3)F_B\overrightarrow{e_x} + (y_2 - y_3)F_B\overrightarrow{e_y} + (z_2 - z_3)F_B\overrightarrow{e_z}}{\sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2}}\right) \\ & + \left(\frac{(x_R - x_1)F\overrightarrow{e_x} + (x_R - x_2)F\overrightarrow{e_y} + (x_R - x_3)F\overrightarrow{e_z}}{\sqrt{(x_R - x_3)^2 + (y_R - y_3)^2 + (z_R - z_3)^2}}\right)\end{aligned}$$

Regarding PAM-CRASH® implementation, it should be applied $\overrightarrow{F_1}$ in the D-ring fixation point in order to simulate a frontal impact to the rail guide.

Assuming the worst case with $\alpha = 30°$, a retractor load of 10kN and including also a safety quotient of 20% in order to guarantee a total feasibility of the part:

$$\overrightarrow{F_1} = -1.25kN\ X + 7kN\ Y - 5.85kN\ Z$$

As final step, after all parameters input, it is necessary to run the simulation. For this case was choose a nonlinear explicit dynamic simulation with load control, due to the fact it is necessary to evaluate the behavior of the part, more specifically the displacement and possible rupture of the component during load increase in order to simulate a vehicle frontal impact. This kind of simulation allows analyzing how much load can the structure support before global failure occurs, as well as a combined strength and stability analysis in which progressive deterioration, e.g. cracking, is considered. It was also selected the Crash solver model, which is already pre-programmed in PAM-CRASH® for this kind of simulation, as it is possible to visualize in Figure 108.

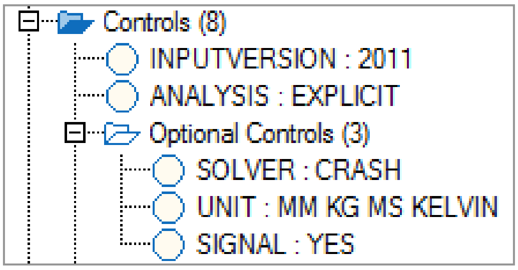

Figure 108: PAM-CRASH® explicit dynamic simulation input.

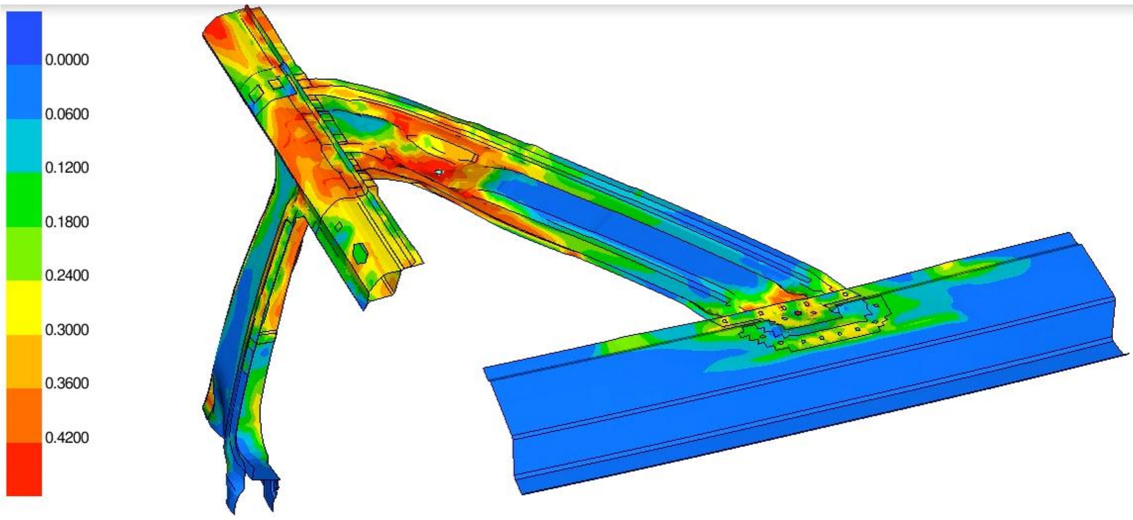

Figure 109: Representation of a Frontal impact simulation and consequent deformations to guide rail. (*Volkswagen Simulation Department*)

As it is possible to analyze after the Finite Element simulation, and as expected before, the area where there is the biggest deformation is where the major loads are applied to the part during a frontal impact, exactly the seat belt D-ring fixation.

Considering the a body block load of 13.5kN as requested from ECE R14, the component shows any crack, with a displacement in the D-ring fixation area of approximately 0.45mm, Figure 110, which is acceptable for this kind of impact.

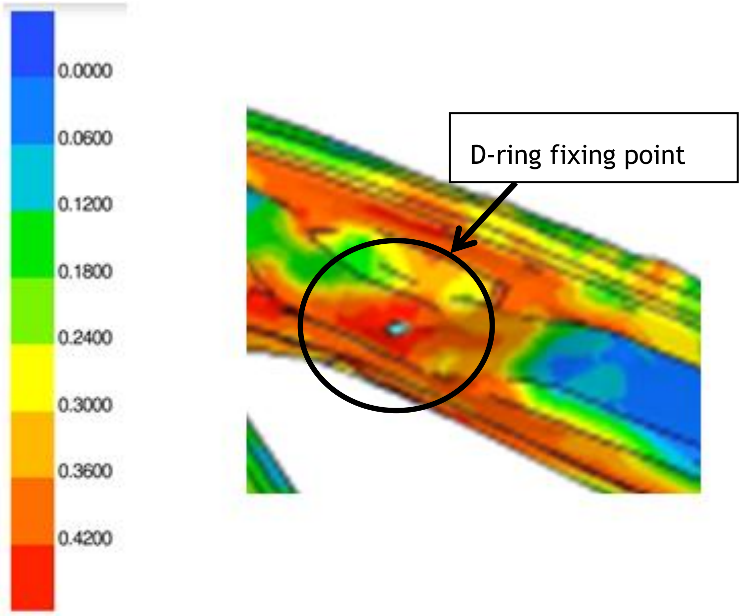

Figure 110: D-ring fixation point and consequent deformation during a frontal impact. (*Volkswagen Simulation Department*)

Also the connection between the guide rail and the rear cross member is an affected area, due to the fact the retractor is positioned in this location and Volkswagen Sharan has an automatic seat belt, which applies a load between 8kN and 10kN during a frontal impact, in order to retain the seat belt and do not let the passenger move forward due to the inertia force. This retaining load is directly applied to the guide rail, deforming it near the contact area between this component and the rear cross member, Figure 111. As analyzed before, for a body block load of 13.5kN, the maximum displacement in this area is around 0.48mm, which is also acceptable and approved in terms of part development.

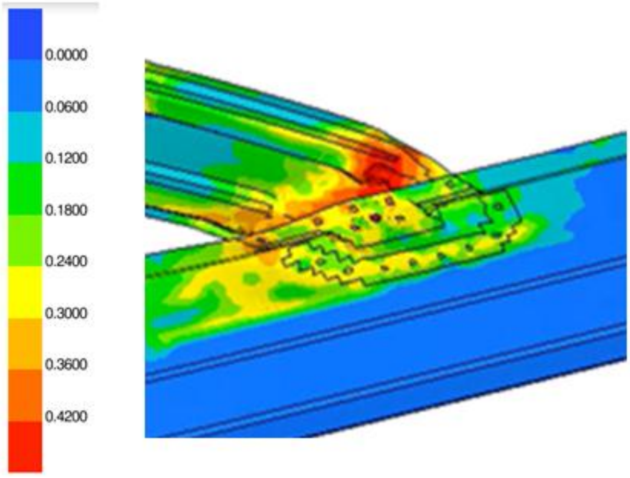

Figure 111: Retractor fixation point and consequent deformation during a frontal impact. (*Volkswagen Simulation Department*)

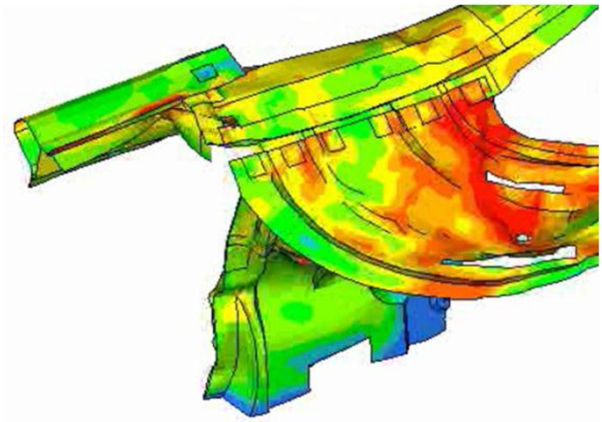

Figure 112: Possible cracked area on C-pillar after a front impact Finite Elements simulation. (*Volkswagen Simulation Department*)

PAM-CRASH® also provides as result from FE simulation, the applied loads time history, where it is possible to analyze the part behaviour, i.e. the displacement of the affected area, during the load application, Figure 113.

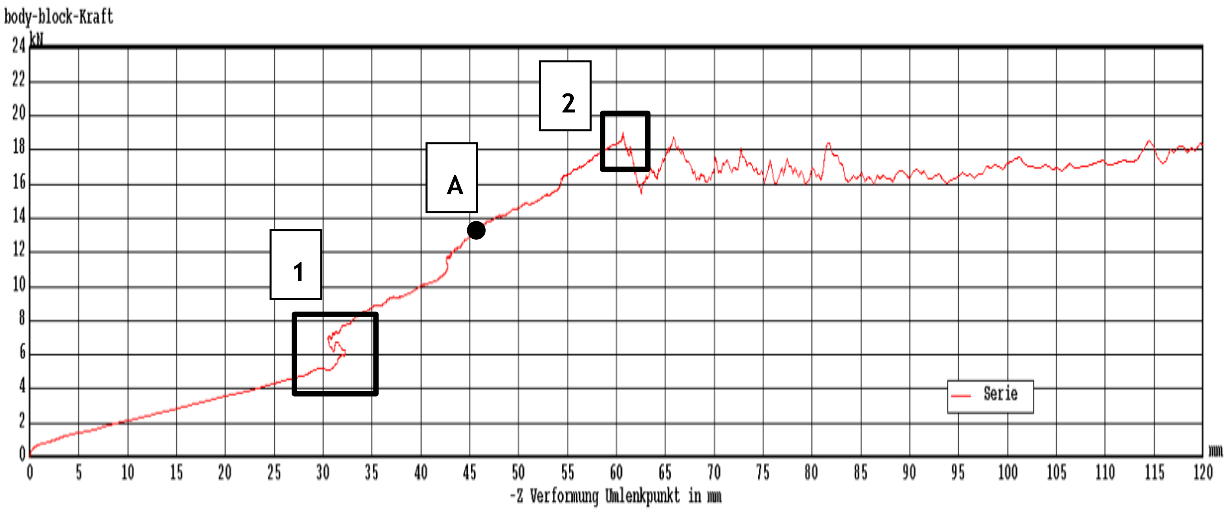

Figure 113: Equilibrium path or Plot with representation of the response (load-displacement) diagram that characterizes the load application on the D-ring fixing point. (*Volkswagen Simulation Department*)

Analyzing the provided plot, Figure 113, the part has an initial linear response till the critical point, detail 2 Figure 113, situated at maximum load requested, 18.9kN (as referred before, $\overrightarrow{F_1}$ = 13.5 + 40% = 18.9kN). After the 140% limit, the part shows a plastic behaviour, and as visualized by Figure 112, not due to the guide rail has a crack but because another part from this reduced model did not resist to the applied loads. However it is also possible to identify, detail 1 Figure 113, a called "snap-back" phenomena, which occurs if the increment of deformation associated with unloading of elastic and undamaged inelastic elements (this is a negative increment of deformation since it is in the direction opposite to that of the initial loading) is greater than the increment of deformation associated with elongation of the damaged inelastic element. This phenomenon could appear when the element size is too small or the mesh has an instable configuration. Taking a look to Figure 97, the mesh near D-ring fixing point is no homogenous, which could contribute to this behavior. Although, and analyzing the displacement of the system load controlled through a small movie is possible to visualize that also the rear cross member near the contact area with the rail guide has a flexible behavior, which could also contribute to this phenomenon.

Also important to analyze is the point A on Figure 113, which represents the requested load of 13.5kN from ECE R14 that the component should resists to be considered able to use in a normal production vehicle. According to the simulated results, at this instant the part has a displacement of 46mm, which is considered acceptable for this kind of systems.

With these results it is possible to conclude that the rail guide with the actual geometry and the actual material characteristics is according all the safety and internal Volkswagen standards, in order to be used in a production vehicle.

4.4 - Deformations Confirmation After a Physical Crash-Test

Considering the virtual simulation explained before, one of the best tools used nowadays to analyze a vehicle impact and the behavior of the different parts that constitute it, all new vehicle models must pass certain safety tests before starting their production. However legislation provides a minimum statutory standard of safety for new vehicles, and in order to encourage manufacturers to exceed those minimum requirements, there are several institutes that perform specific tests that could compare different vehicles and their safety features, giving to the final consumer an amplified overview regarding these issues.

In Europe, Euro NCAP is the official organism authorized to perform this tests and also to classify each vehicle according to their results. Today, more than ever before, safety sells vehicles and for buyers it is a key element of their purchasing decision.

One of the most important tests, and already announced before, is the frontal impact test. Euro NCAP perform this test, based on the one developed by European Enhanced Vehicle-safety Committee as basis for legislation, but in this case the impact speed has been increased in 8km/h.

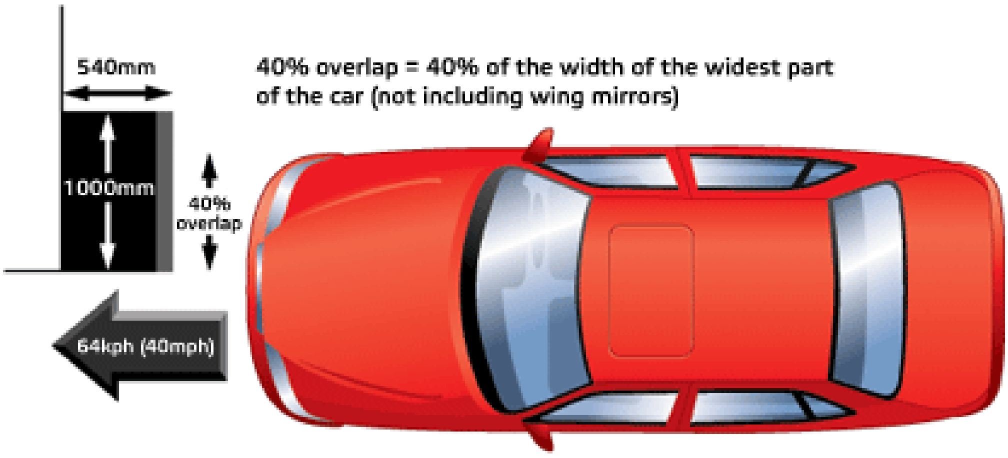

Figure 114: Euro NCAP frontal impact test overview. (*Euro NCAP website*)

Each tested vehicle is subjected to an impact into an immovable block fitted with a deformable aluminium honeycomb face, which is intended to represent the most frequent type of road crash, resulting in serious or fatal injury. This simulates a frontal impact between 2 vehicles of similar mass, where is offset to replicate a half width impact between them, which means, this is replicated by having 40% of the vehicle impact the barrier. The barrier face is deformable to represent the deformable nature of the vehicles.

The test speed of 64 km/h represents a 2 vehicles collision with each one travelling at around 55 km/h. The difference in speed is due to the energy absorbed by the deformable face. Research has shown that this impact speed covers a significant proportion of serious and fatal accidents. By preventing intrusion, the chances of the occupant impacting the vehicle’s interior is minimised with space remaining for the restraint system to operate effectively.

For a restrained occupant, the deceleration forces, generated in the crash, are transmitted to the occupant through the restraint system. Euro NCAP has encouraged the adoption of seat belt pretentioners, load limiters and dual stage airbags, to help attenuate the forces transmitted to the occupant.

Also 2010 Volkswagen Sharan was subjected to this front impact test, fulfilling it with an impressive 5 stars final result.

Figure 115: 2010 Volkswagen Sharan during a front impact test. (*Volkswagen Body Engineering*)

As said before, these kinds of tests are used to submit a vehicle regarding safety issues, and due to the fact that the rail guide studied in this project has crucial importance in this subject.

After submitted to a frontal impact test, the results from guide rail were exactly the expected, taking in mind that the entire component was design and developed in order to preform without any problem the ECE R14 test.

a) b)

Figure 116: a) Guide rail before performing a frontal impact test; **b)** Guide rail after performing a frontal impact test. (*Volkswagen Simulation Department*)

The guide rail shows a displacement around 39mm in Z direction in the D-ring fixation area, which according to the developed part matches with an applied load of maximum 9.7kN. With this result, is it possible to say that the component and all the group of parts were the guide rail is connected is able to perform a frontal impact almost 1.4 times higher as requested. Also, there was not found any cracks on the part, even in the most requested area, the seat belt D-ring fixation point.

However, and as it is possible to perform the ECE R14 test internally in Volkswagen safety dynamic tests department, after it the guide rail should be disassembled from the vehicle and deeply analysed in order to see if there are any microscopically cracks or if there are some other areas were the deformation was higher than expected and also the part thickness was reduced to critical levels.

5

Part Improvement

Abstract: In this chapter, it is shown possible designs from the actual rail guide in order to improve it with the minimum investment as possible. New geometries, materials and thicknesses were studied, with the final goal of choose the best improved design. The final project feasibility, including supplier offer for different improved situations, is also shown and explained.

5.1 - Introduction

As described in chapter 2 and 3, the improvement process has several constraints, and two main objectives: reduce the mass with the minimum final price per part.

The improvement process was made evaluating:

- Different geometries
- Materials
- Metal sheet thickness

5.2 - Improvements Possibilities

At a first look to the actual stamping process from the guide rail, it would be possible to visualize that it will be hard to incorporate some improvements in the actual tool, which has no free operations and all new improvements in order to have a lighter part, would request some investment.

Already discussed, the following constraints affect geometry, and presented on Figure 117:

- Main geometry modifications: As analyzed in chapter 2, the main geometry must be keep in order to maintain the current characteristics of the component as well as avoid excessive investment changing parts nearby.
- Matching areas: If the contact areas between the component in study and other connected parts are changed, it would be necessary to increase the investment in order to modify them. On Figure 117, matching areas between the rail guide and the C-pillar and rear cross member, between the part and D-ring fixing point or the seat belt guides fixations, must be keeping as in current part.
- Spot weld locations: It is necessary to ensure that all the spot welds are according to the standards in terms of correct diameter as well as distance between them and to the edges of the part. New locations are possible, but the current norms must be followed.
- Possibility to reuse the current stamping tool: All the foreseen improvements must be thought in order to reuse the current stamping tool. Geometry, material and thickness modifications must be carefully planned, in order to keep the investment as lower as possible.

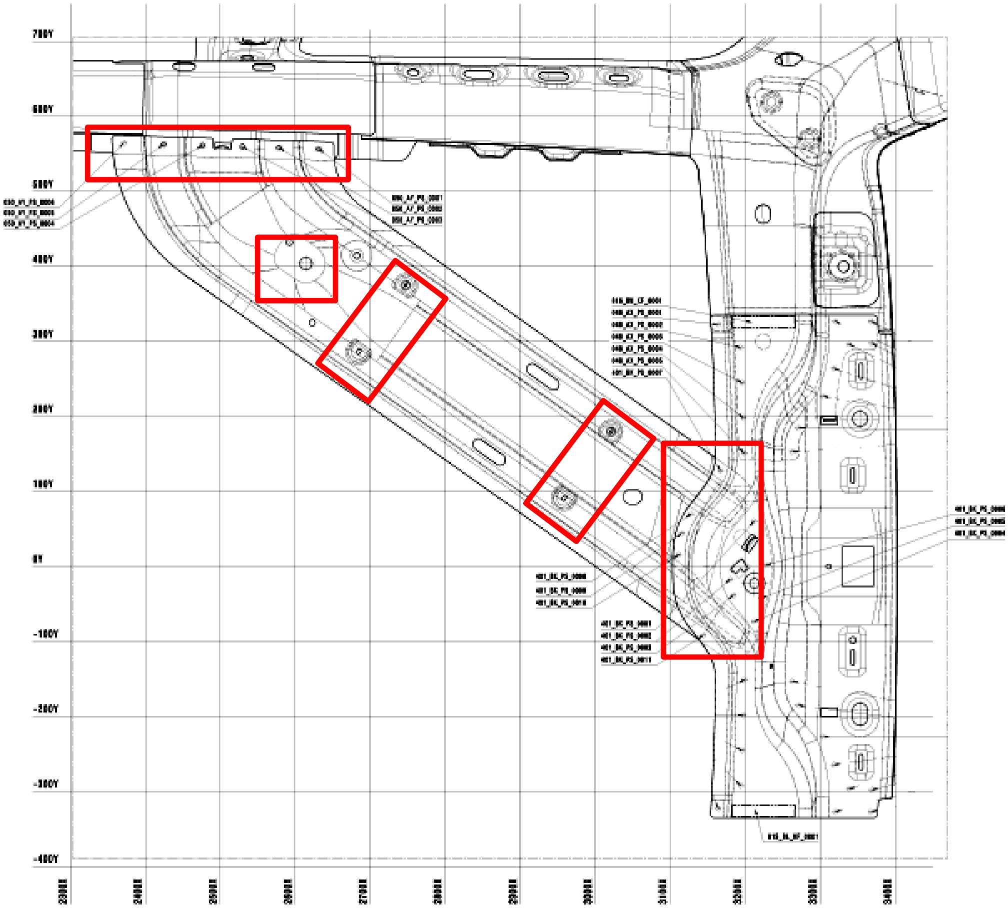

Figure 117: Main contact point between rail guide and other components. (*Volkswagen Body Engineering*)

Therefore it is possible to remove material without affecting the mechanical strength of the component. This kind of improvement must be deeply analyzed to guarantee that the stamping process is feasible.

Also premises regarding material and thickness improvement must be taken into account.

Material modifications:

- Exclude material that may present welding problems: Some materials, like hot forming ones, are not compatible with the current welding process in the supplier or in Autoeuropa, which will automatically request more investment in order to adapt both processes to the new characteristics.

- Mechanical strength of the component: Material must be choosing in order to keep the main function of the part and similar strength characteristics.

- Reuse stamping tool: Materials characteristics must be analyzed in order to be compatible with the current manufacturing tool.

- Raw material price: Material changes must take into account the raw material price in order to keep the price per unit from the improved component lower as possible.

Thickness modifications:

- Reuse stamping tool: As well as for material modifications, thickness improvements must be analyzed in order to be compatible with the current manufacturing tool.

- Mechanical strength of the component: Thickness must be choosing in order to keep the main function of the part and similar strength characteristics.

Each one of these possible modifications is presented in the following sections.

5.3 - Geometry Improvement

As described before there are several ways in order to improve the component in study. However and regarding all constrains present on the actual concept, the best solution founded was a lightweight design, including minimal changes regarding material specifications, i.e. avoid to use materials like aluminum or hot forming, and also trying to keep as much as possible the current processes not only in the supplier, where the part is built, but also in Volkswagen Autoeuropa, where it is integrated in the Body structure.

In order to achieve this proposal, it was necessary to create a new design with a similar geometry, mainly maintaining the same contact areas. Regarding material it is possible to find a lighter material but as discussed before, it should be compatible with the actual Body construction process, keeping the investment lower as possible.

In order to have a bigger range of improvements possibilities, it was decided to create 2 different solutions:

- Version A: In this concept the entire part must be revised in order to remove the maximum material as possible.
- Version B: The main geometry must be keep, incorporating only new holes in order to reduce the total mass from the part.

Figure 119 and Figure 118 show respectively Version A and Version B from the improved designs.

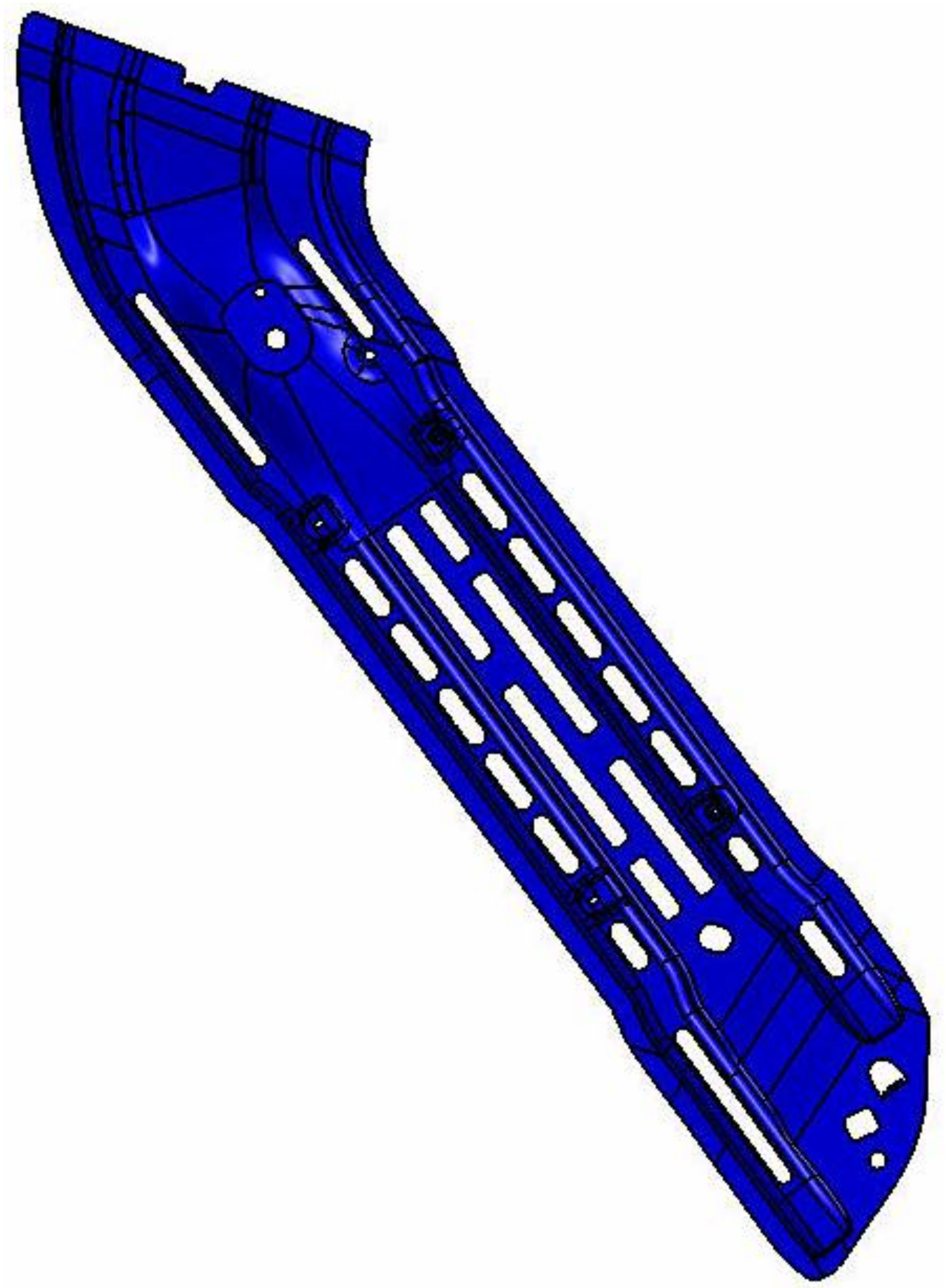

Figure 118: CAD representation from improvement possibility Version A.

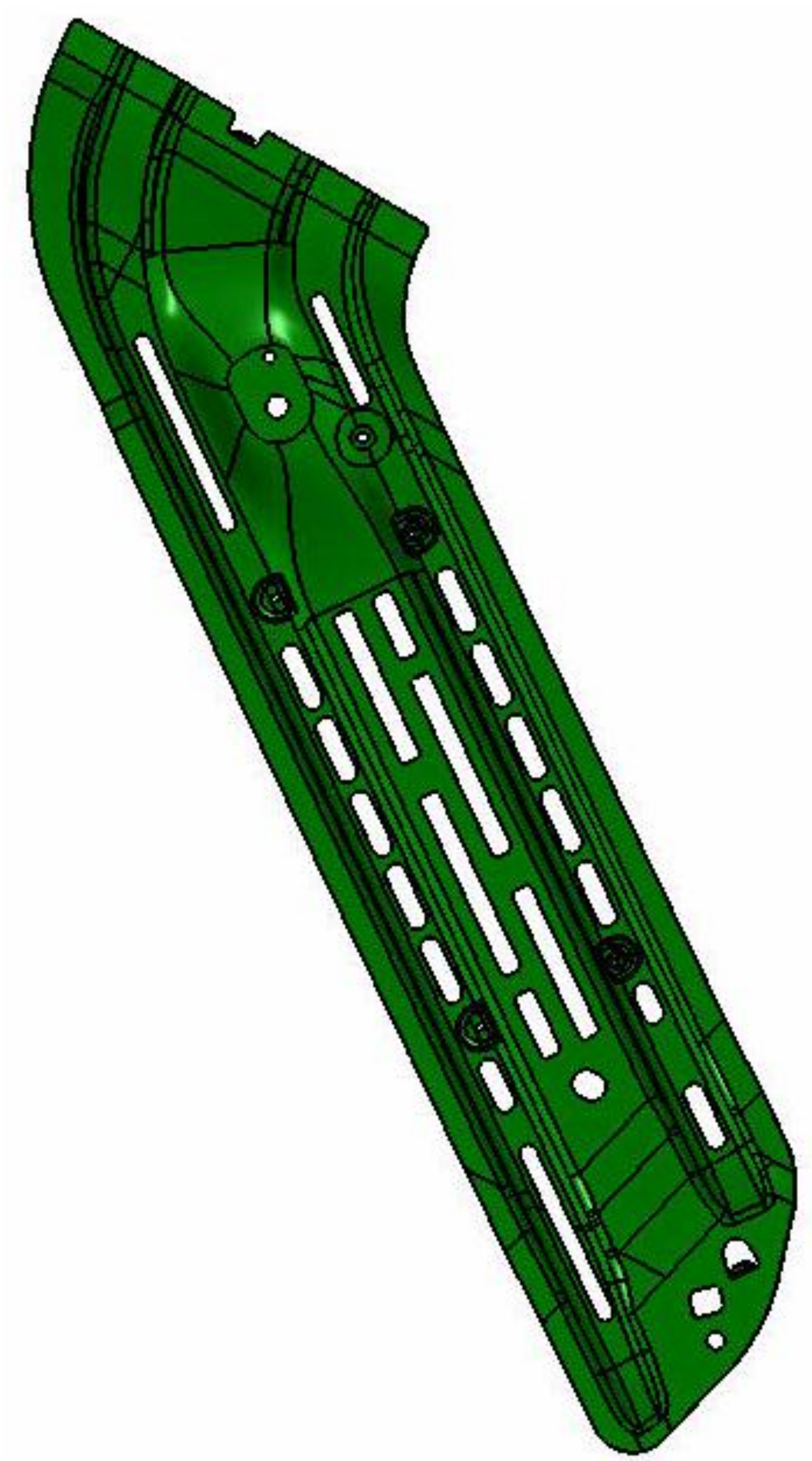

Figure 119: CAD representation from improvement possibility Version A.

Version A

This concept was the first to be developed, and also the one with more relevant modifications comparing to the actual part.

As discussed before on 2.4 Constraining, in order to have the lower investment as possible, all the contact areas between the component and the body structure should keep the same shape as actually.

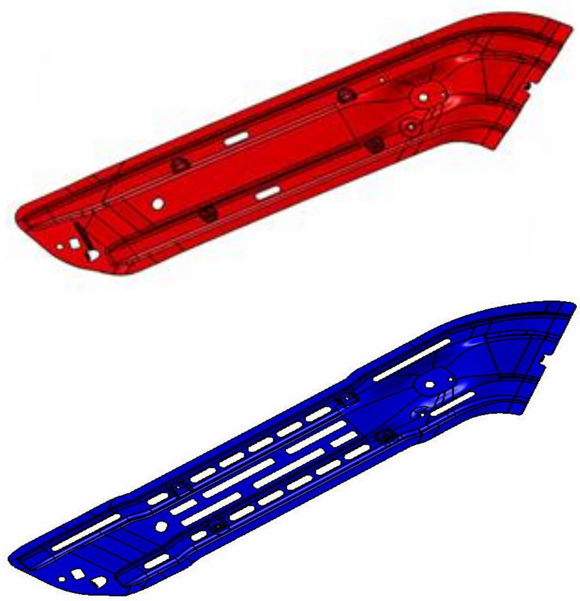

Figure 120: Comparison between actual part (red) and Version A improvement (blue).

Taking this idea in mind, and as it is possible to analyse in Figure 120, the 2 main contact areas were remain almost without changes. It was only made little improvements, in order to use less material.

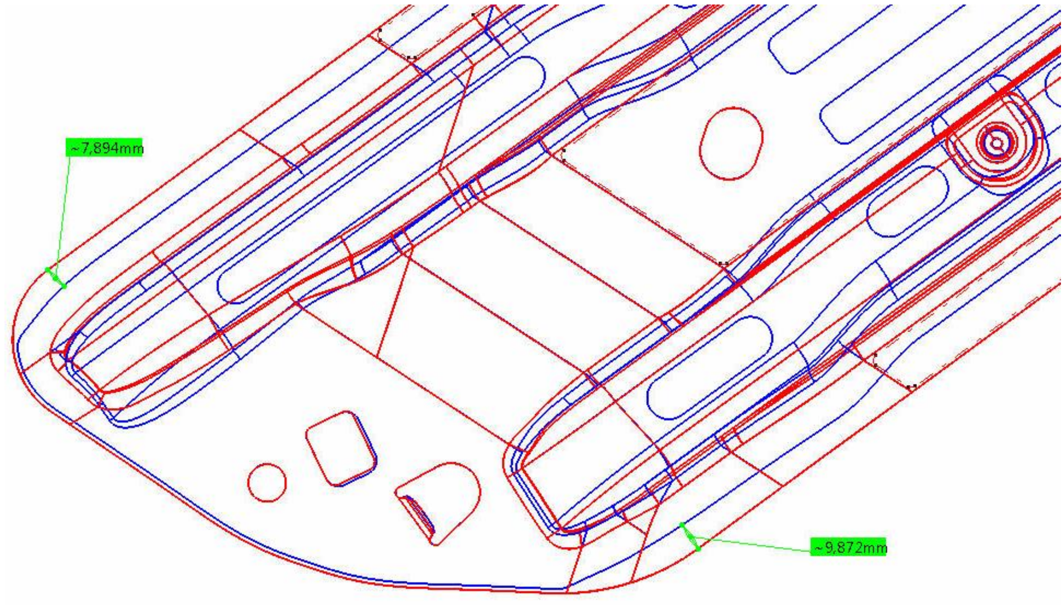

Figure 121: Comparison between actual (red) and improved part (blue), on rear cross member area.

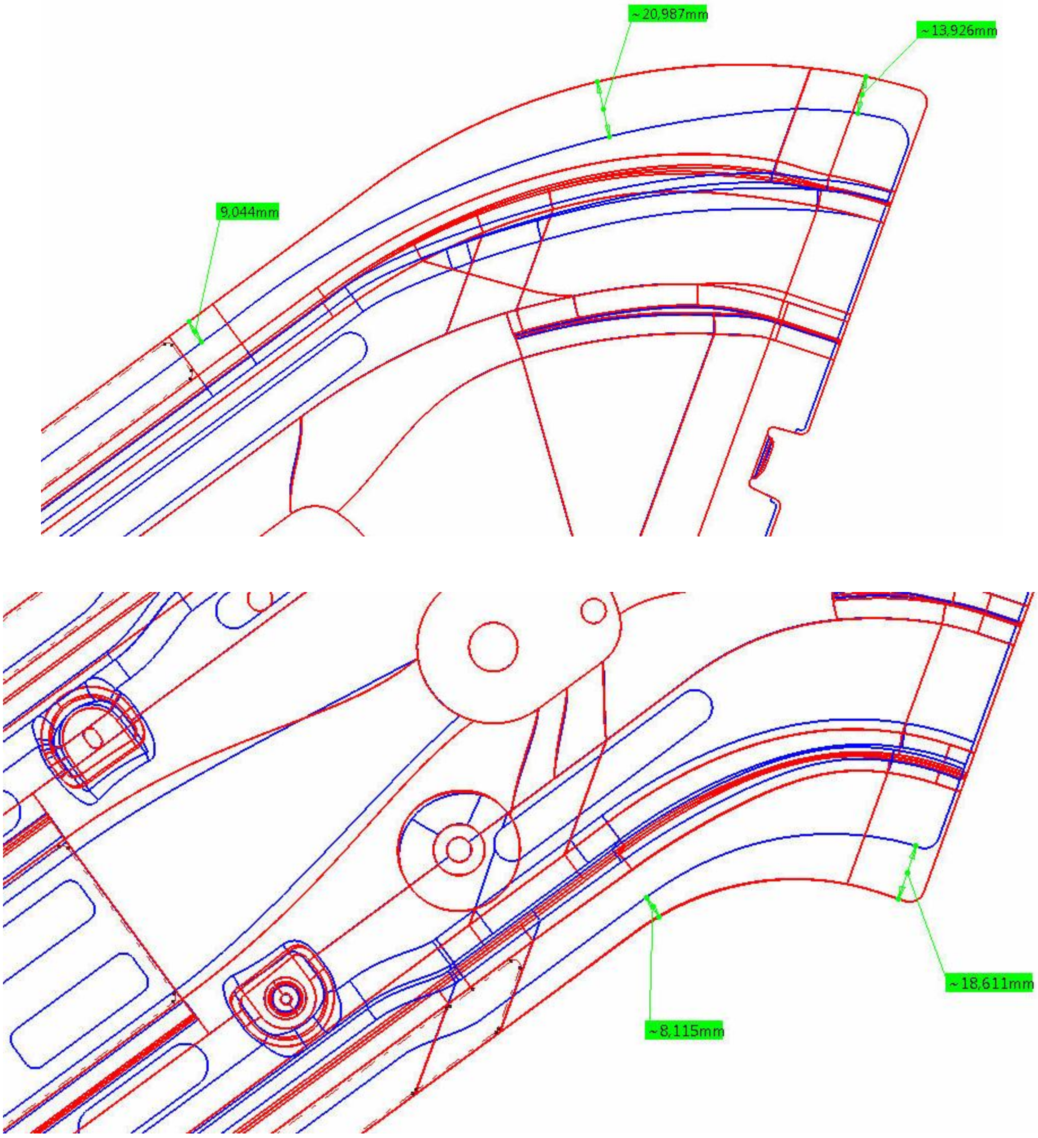

Figure 122: Comparison between actual (red) and improved part (blue), on C-pillar area.

Taking a detail look to Figure 121 and Figure 122, in average was improved approximately 8 mm of flange on the rear area and 13 mm on the C-pillar area, divided by areas where was possible to reduce almost 20mm and another ones where the improvement window was smaller. The initial blank necessary to stamp, could be improved in order to save money regarding raw material due to the part is smaller.

Analysing both Figure 121 and Figure 122 on above, and keeping in mind the standards already discussed on 3.4 - Welding Connections in the Actual Part and 3.5 – Welding Connecting From the Actual Part to the Body Structure, there are 2 important aspects that should be considered: contact surfaces and area to spot welds. In this case, the contacting flanges to the roof on the middle section of the part, was possible to reduce the actual 16,94mm flanges to the minimum of approximately 15mm, because it is only necessary to have contact between both parts without a minimum specification, where it should only have the possibility to apply a standard glue seam.

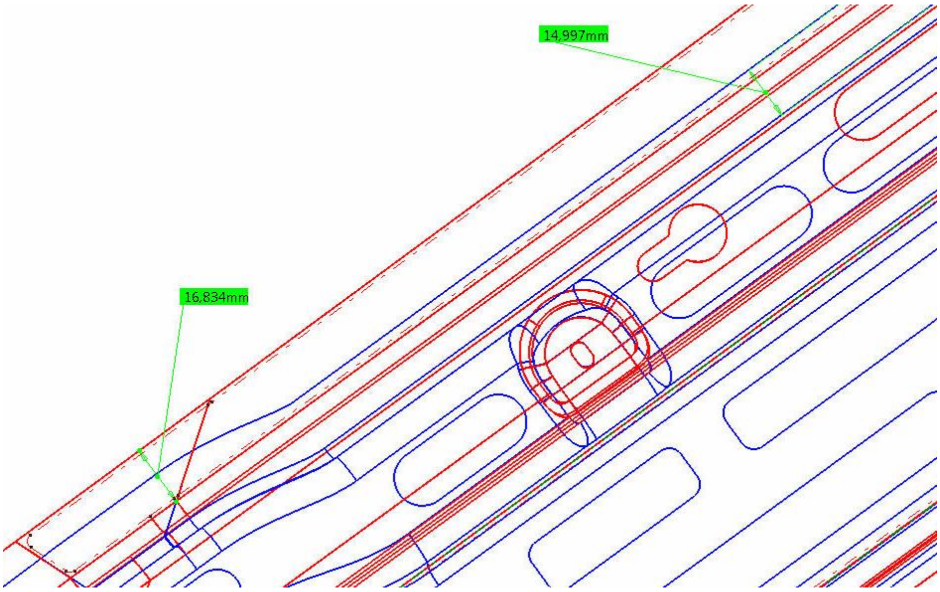

Figure 123: Comparison between actual (red) and improved part (blue), on contacting flanges middle area between Rail Guide and Roof.

Reducing flanges, forces to recheck the position of spot welds. Improving the part to the new geometry showed above, it was necessary to readjust two spot weld in order to be acceptable according to welding norms. Figure 124 show the reposition of the spot weld number 050_AY_PS_0006, +3mm in X direction, and spot weld 050_AY_PS_0001, -4mm in X direction, in order to be according welding standards, where a spot weld, according to Table 6, must have a minimum distance of 4.3mm to the edge of the flange. This kind of change is easy to do and does not need special investment, due to the fact that it is only necessary to change the robot program, requesting few hours with one robot programmer.

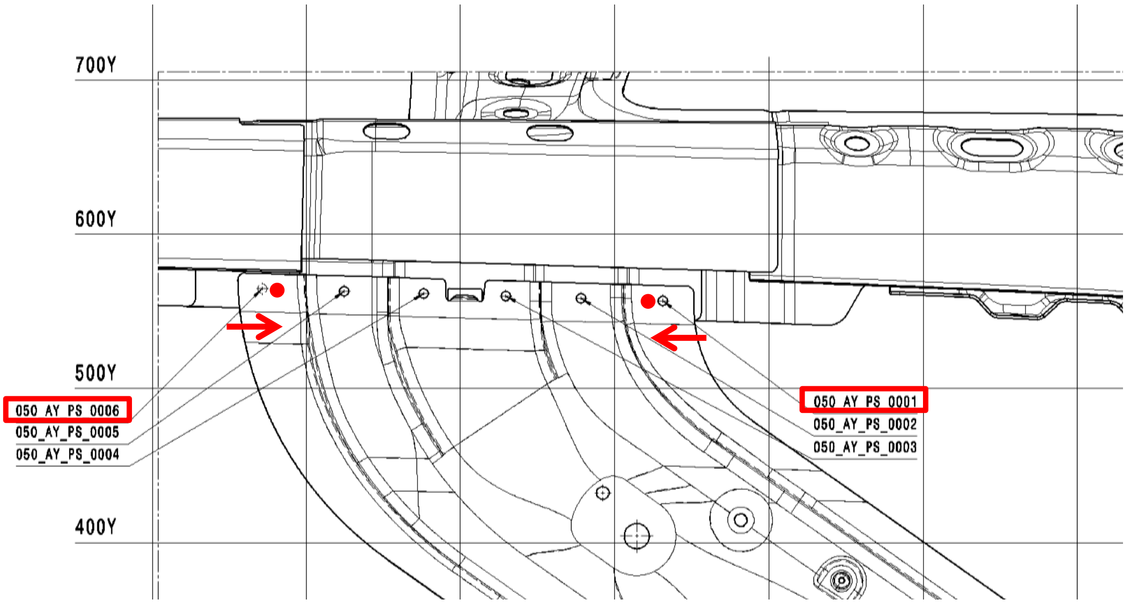

Figure 124: Reposition of a spot weld regarding flange dimension improvement. (*Volkswagen Body Engineering*)

Analysing now the middle section of the part, and as seen on 4.3 – Virtual Major Deformations, the area where the seat belt D-ring is fixed to the guide is the most area with biggest deformations, and in order to keep the same stiffness as the actual part, this particular section must keep the same geometry. Consequently, no kind of improvements were made in this area.

On the other hand, the middle channel where passes the seat belt from rear area where is the retractor to the D-ring fixation, is possible to be redesign taking only in mind that it would be necessary a straight line of material along all part in order to be possible to flow the internal forces inside the part during an impact, without any substantially deformation in the component or in an extreme case, cracking it.

With this, the middle channel was improved integrating 2 different ideas:

Holes introduction: where 6 new holes were introduced in order to reduce weight. This kind of improvement could be easily implemented in the stamping tool, where divided by several operation, it could be integrated without building a new tool and it would not be necessary to change stamping forces, due to the fact that they would not be done simultaneous. A bigger part of raw material would be scraped, however in this case or comparing to the current part, both would request the same amount of material, which means that the price paid per unit regarding raw material is the same. In this case, the scraped material could be sold; saving money, as well as the component is lighter.

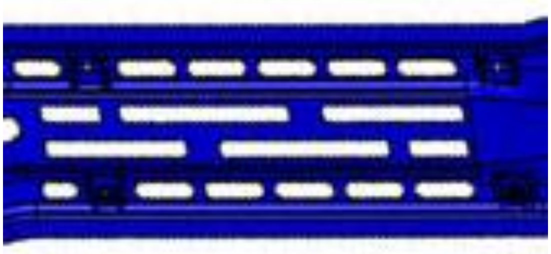

Figure 125: Detailed view from the new holes implemented.

Theoretical, this kind of operation could be performed after stamping process in a new unit used only to make the holes in the part, keeping the actual tool without any changes in this field. However, it would request investment for the new operation, free space inside supplier facilities and also man power to perform the operation, which will increase not only investment but also price per unit.

Figure 126 show the improvement done on middle channel width. This area was reduced from 66.7 mm to 57.4 mm, taking as premise that the seat belt has 47 mm ±1 mm, and considering a safe coefficient of 20%, due to the XY movement that the seat belt could do without getting stuck.

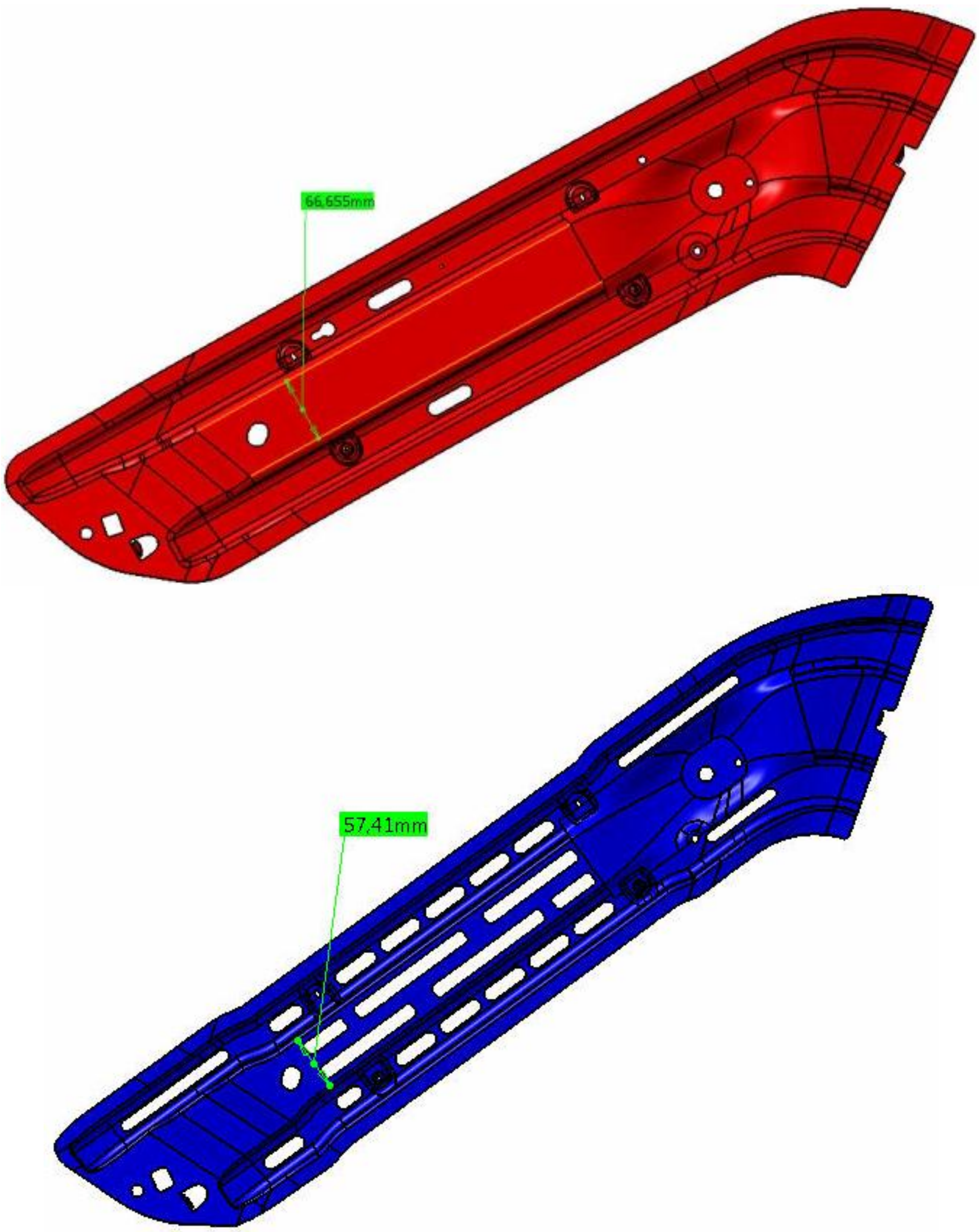

Figure 126: Version A middle channel width improvement.

Analysing now the 2 side reinforcement channels, it is possible to visualize that they are needed in order to guarantee the part's torsion and flexion resistance, however they could have a smaller width and also their geometry could be improved.

The actual geometry has reinforcement channel with 40.3 mm width and was possible to reduce till 39.6 mm.

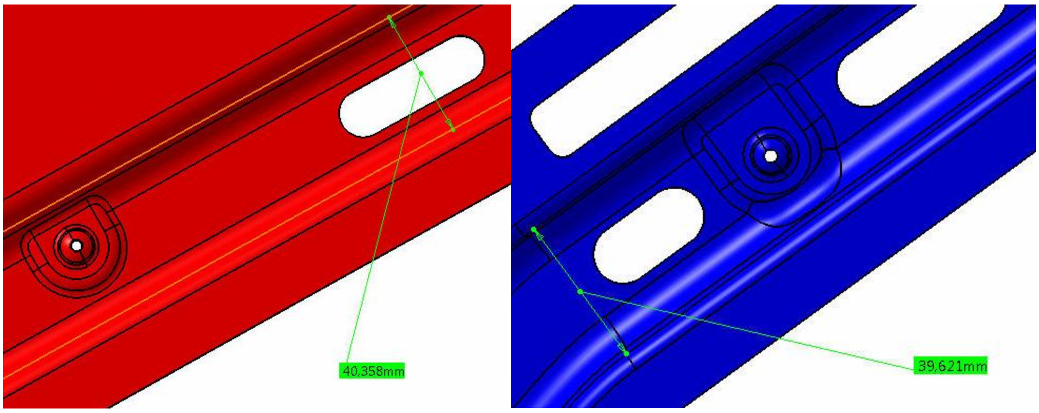

Figure 127: Comparison between actual (red) and improved part (blue), on middle section reinforcement channels.

It is not possible to reduce more, due to the fact that in these areas are the 4 fixing points to the seat belt guides, Figure 128, and according the previous experience, this area has a big interception of radius, from the channels itself and also the “castles” for the guides fixing points. Regarding this aspect, the part could be not feasible in terms of stamping process, if the reinforcement’s width is reduced to extreme levels.

Figure 128: Actual reinforcement channel with fixation points from seat belt guides.

As described before regarding new geometry premises, the seat belt guides fixations must remain in the actual position. If this premise is not obeyed, it would be necessary to develop new components and automatically the investment cost will be higher.

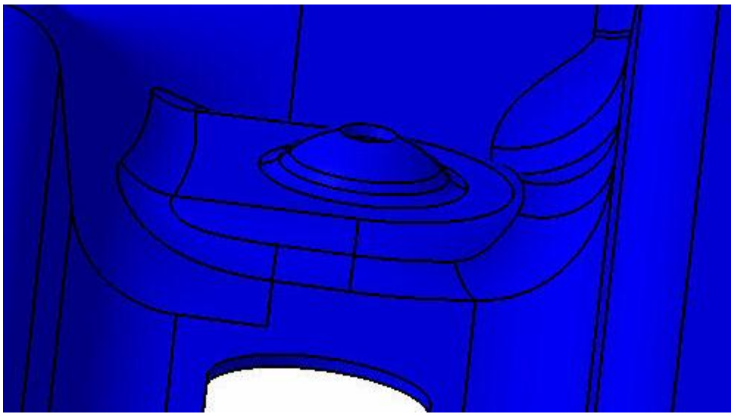

Figure 129: New geometry from the reinforcement channels including guides fixation points.

Not only was the width of the reinforcement channels reduced but also their configuration in order to have a smaller part, as shown on Figure 130.

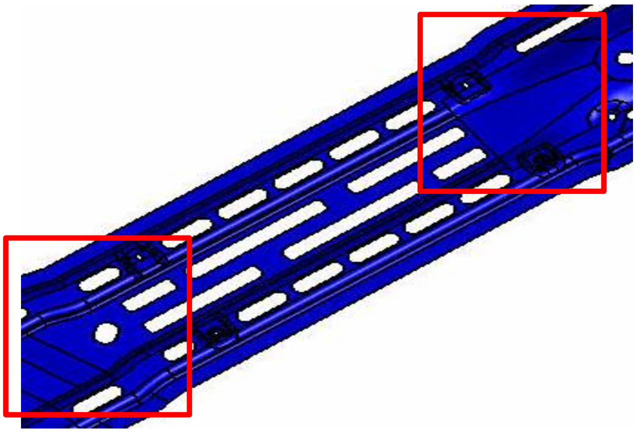

Figure 130: New configuration from the reinforcement channels.

In this case, and considering that this is the best concept, there is enough freedom to change the geometry of the part, were decided to change the straight actual design to a new "S" design in order to save approximately 9mm on the total width of the component in the middle section.

Last consideration about the reinforcement channel, concerns with the fact that the main contribute from the reinforcement channels to the total stiffness of the part, is their 3D design. If there are no reinforcement channels and the part was flat in those areas, due to its length, it would bend and would not have the requested characteristics to its function. However and according the previous experience regarding stamping metal components, the new proposed geometry could be more propitious to appear wrinkles in the part, mainly in the "S" radius concordance area.

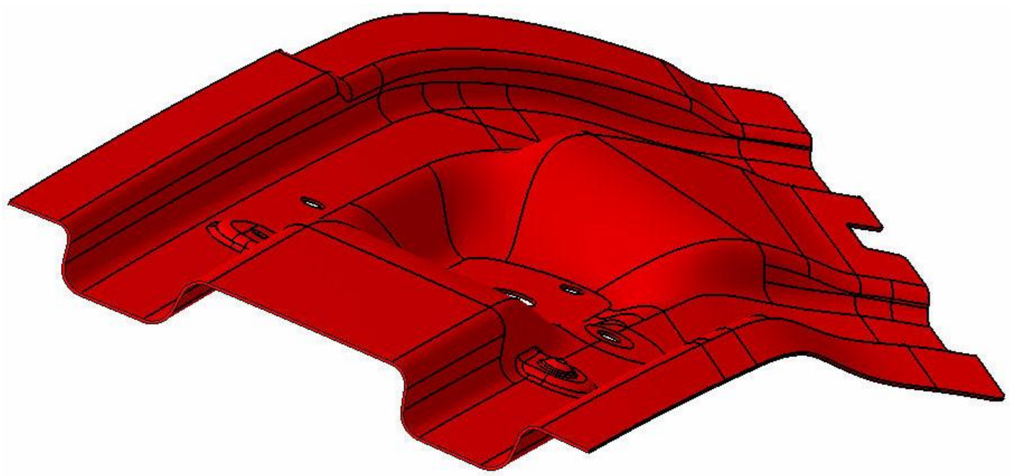

Figure 131: 3D design from the reinforcement channels.

Regarding considerations done before, the middle channel could be improved with some new holes in order to help to decrease the total mass of the part.

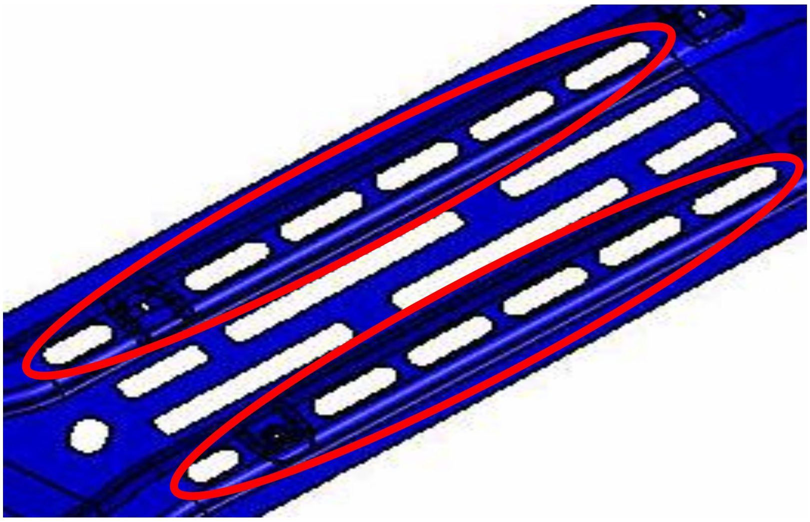

Figure 132: New holes introduction on both reinforcement channels.

As a last option of improvement, was also considered to change the material and / or decrease of material thickness.

Version B

As said before, there was also developed an improved Version B of the current component. This variant proposes to keep the actual geometry, implementing only new holes as in Version A, in order to remove unnecessary material. With this is possible to reduce the actual weight of the part, theoretically keeping the investment lowest as possible, due to minimal changes in the current stamping process.

5.4 - Considering Different Materials and Thicknesses

The selected material and thicknesses are directly related, because in order to get the necessary component strength, thickness reduction must be accompanied by the use of a higher yield stress material.

Considering that the actual part has 1917g and it is made by HC340LA material, there were choose 5 different options with different thicknesses, which are usually used in this kind of applications, in order to preform new material / thicknesses combinations and study their possibilities.

Table 9: Different materials and thicknesses considered to improve the Version A and Version B.

Variant	Option	Thickness [mm]	Material	Tensile Strength [MPa]	0.2% Proof Strength [MPa]	Mass [g]
Current part	1	1.00	HC340LA	400 - 500	340 – 410	1917
Version A	2	1.00	HC340LA	400 - 500	340 – 410	1703
	3	0.90	HC340LA	400 - 500	340 – 410	1574
	4	0.90	HC420LA	460 - 580	420 - 500	1574
	5	0.90	HC340XD	590 - 700	340 - 420	1574
	6	0.85	HC450XD	780 - 900	450 - 560	1338
	7	0.70	TL 4225	1300 - 1650	1000 - 1250	1135
Version B	8	1.00	HC340LA	400 - 500	340 – 410	1784
	9	0.90	HC340LA	400 - 500	340 – 410	1655
	10	0.90	HC420LA	460 - 580	420 - 500	1655
	11	0.90	HC340XD	590 - 700	340 - 420	1655
	12	0.85	HC450XD	780 - 900	450 - 560	1419
	13	0.70	TL 4225	1300 - 1650	1000 - 1250	1216

Table 10: Influences from thickness to areas, volumes and masses considering Version A and Version B of the rail guide.

Variant	Option	Thickness [mm]	Area $[m^2]$	Volume $[dm^3]$	Mass [g]
Current part	1	1.00	0.246	0.492	1917
Version A	2	1.00	0.201	0.402	1703
	3	0.90	0.201	0.362	1574
	4	0.90	0.201	0.362	1574
	5	0.90	0.201	0.362	1574
	6	0.85	0.201	0.342	1338
	7	0.70	0.201	0.281	1135
Version B	8	1.00	0.227	0.453	1784
	9	0.90	0.227	0.408	1655
	10	0.90	0.227	0.408	1655
	11	0.90	0.227	0.408	1655
	12	0.85	0.227	0.385	1419
	13	0.70	0.227	0.317	1216

Considering the different options from Table 10, it is possible to verify that different materials and different thicknesses have directly influence in the total mass of the part.

As expected Version A has better mass improvement due to the fact that the component has an improved design and not only new holes as Version B. The best results were achieved by the material TL 4225 with 0.70mm thickness, options 7 and 13, however this kind of steel request a new stamping process, hot forming, and also the welding process in Autoeuropa must be updated in order to receive this new kind of material.

Considering only materials and thicknesses, options 2 and 8, could keep the same stamping tool as well as the same welding process, due to the fact that material and thickness is currently used in actual part, however options 3 and 9, would request a new stamping tool because the current one is not prepared to a different thickness as

1.00mm. For these last 2 options, welding process could be exactly the same. It would only be requested some parameters adjustments regarding new thickness.

The other options presented on Table 9, request new stamping tools due to material and thickness changes as well as it would be necessary to recheck the entire welding process in Autoeuropa, with necessary investment included.

5.5 - Simulations

On chapter 4.3 - Virtual Major Deformations, was explained how to perform in order to due to a Finite element model, studying the behavior of the guide rail during a virtual frontal impact test.

Keeping the same philosophy, and in order to validate the improvements proposed to the part in study, it is necessary to perform similar simulations for each improvement option.

A reduced detailed multi-proposed finite element model of the improved rail guide was developed using the same specifications as presented on 4.3 - Major Virtual Deformations, and keeping those specifications, would be possible to analyze and directly compare all the cases, in order to see the main differences between them.

With common agreement with Volkswagen’s Simulation Department, it was decided to present in this chapter the simulation from the best improved design regarding mass improvement and associated costs. Considering that materials like TL4225 would increase the price per unit as well as all the stamping and welding processes should be also redesigned with associated investment, this option must be analysed as a case study and not a real improvement proposal for this project. Regarding this budget restriction the second best option found on Table 9, shows the Version A considering HC450XD material with 0.85mm thickness.

Figure 133 presents the reduced model from the guide rail area, simulated in this chapter. Comparing to the chapter 4.3 - Virtual Major Deformations, the model used is basically the same, including only the new geometry from the component in study.

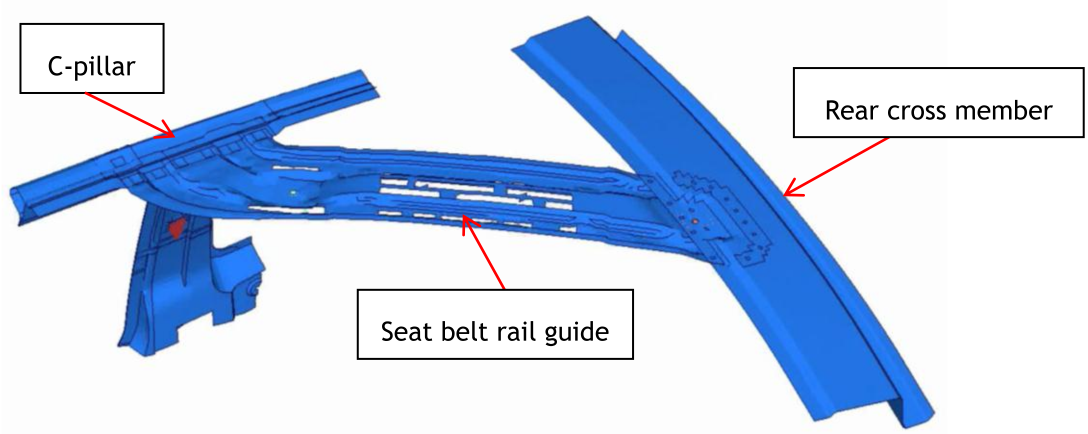

Figure 133: Reduced model, contemplating only the improved guide rail and the other parts where it is connected.

As made for the current part, this model was meshes using ANSA® software, keeping the same premises as before in order to try to have equivalent discretization to the simulation done before. Due to new geometry, the mesh should also be different as before, however is important to guarantee calculation precision similar to the previous example, in order to be possible to have a direct comparison between both models.

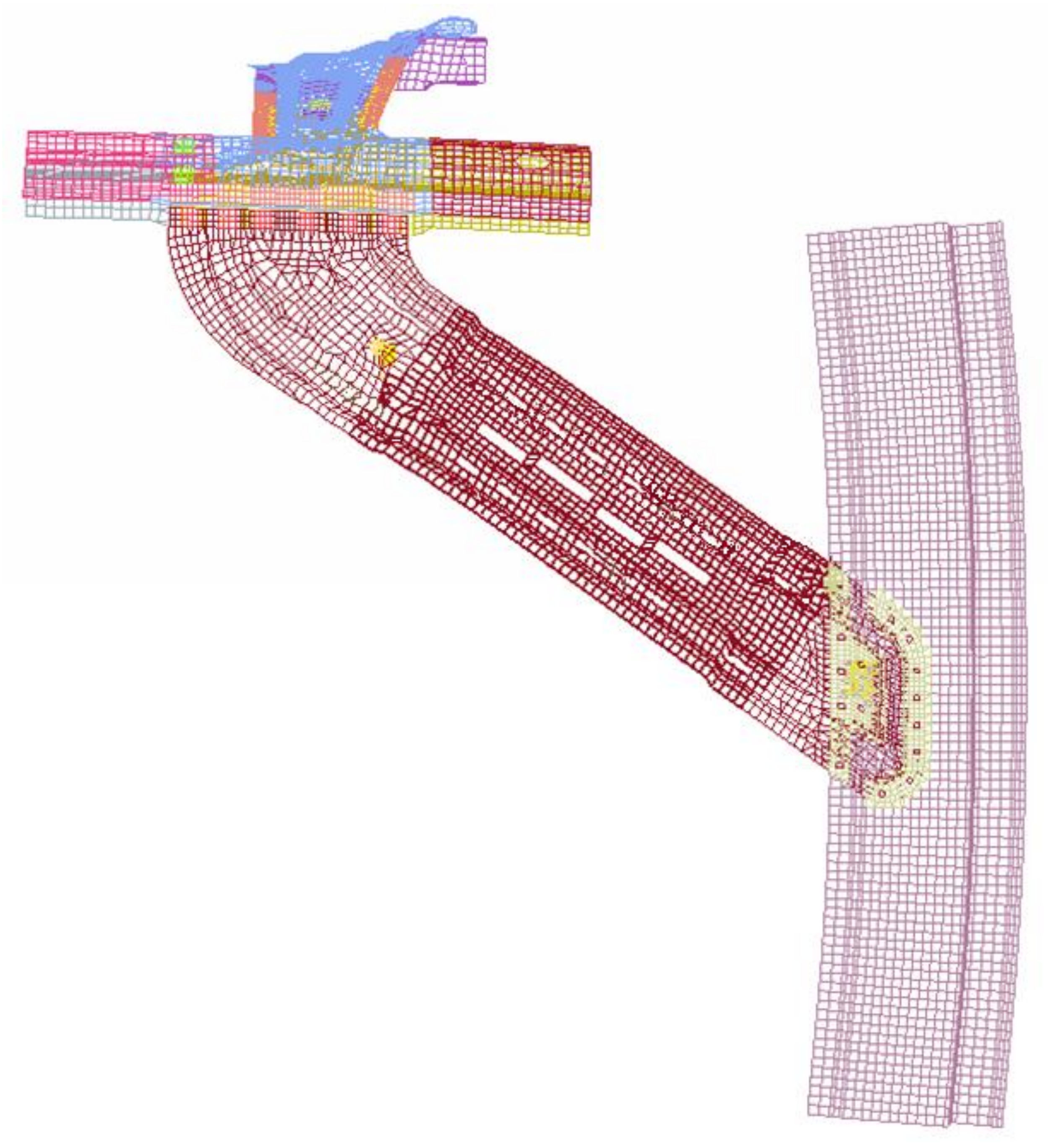

Figure 134: Mesh model modeled using Visual-Mesh application. (*Volkswagen Simulation Department)*

As processed on chapter 4.3 - Major Virtual Deformations, boundary conditions and applied loads were keep the same for these simulation, however, as described by Figure 124, there were two spot welds, which position must be readjusted. Considering the input file that PAM-CRASH® automatically create with each new simulation, this process is easier to perform, where the user just need to change the coordinates of the requested item to the new ones.

Figure 135 reports the results from the proposed simulation, regarding the displacement on the D-ring fixing point during the load application till maximum of 18.9kN as requested:

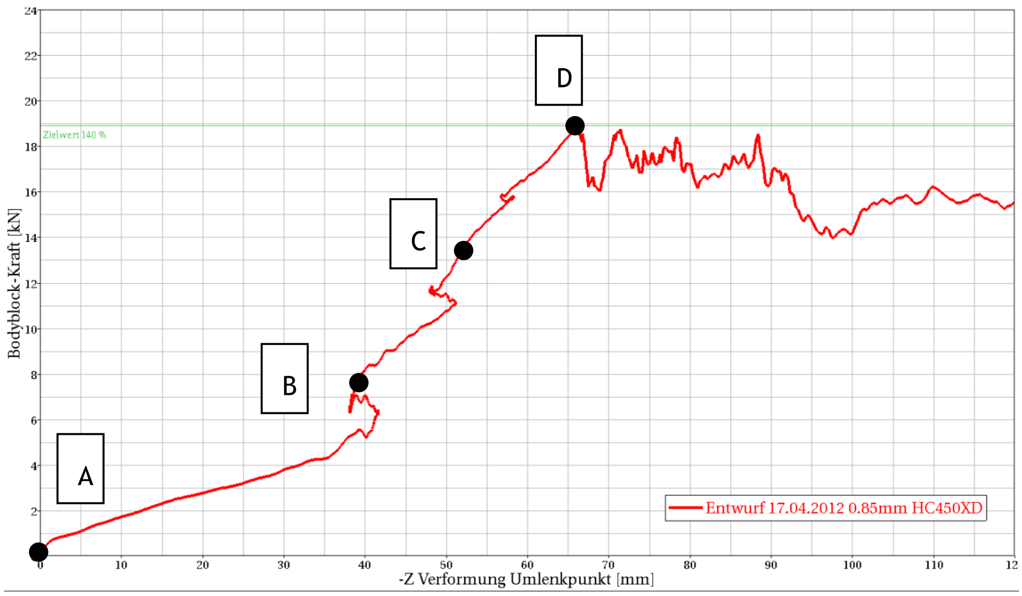

Figure 135: Plot with part displacement during load application. (*Volkswagen Simulation Department*)

In order to have a deeply analysis regarding the behaviour of the system, four different instants in strategic points were choose. Figure 136 shows the graphic representation from Detail A on Figure 135, where it is possible to visualize the initial moment from the simulated with displacement equal to zero in all the system.

Figure 136: Graphic representation from Detail A on Figure 135, regarding displacement [mm]. (*Volkswagen Simulation Department*)

Figure 137 represents the system after the first “snap-back”. Considering this point, D-ring fixation has at this moment 39.3mm for a considered load of 7.5kN.

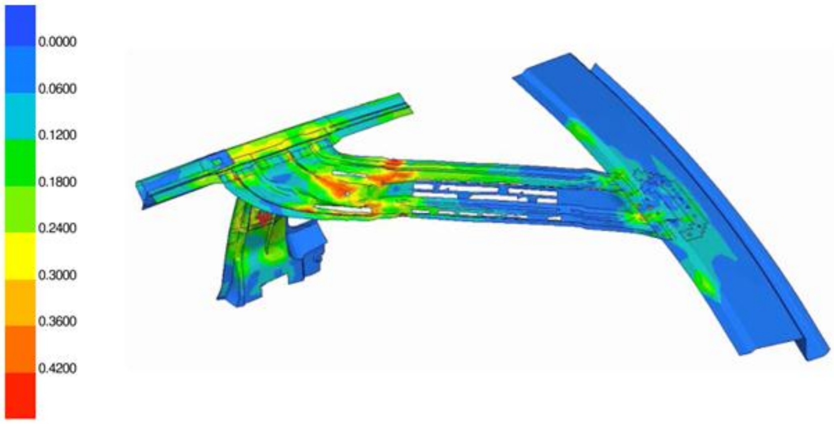

Figure 137: Graphic representation from Detail B on Figure 135, regarding displacement [mm]. (*Volkswagen Simulation Department*)

Detail C from Figure 135 represents the simulated displacement from the D-ring fixation considering the requested load from ECE R14, 13.5kN. As it is possible to analyze, in this point the component shows a deformation of approximately 52mm in Z direction.

However it is also interesting to analyze the difference between the simulated displacements from the current part to the improved design. The component shows a worst result, approximately 6mm, which was expected taking in consideration that the proposed design, with less material has an inferior strength resistance.

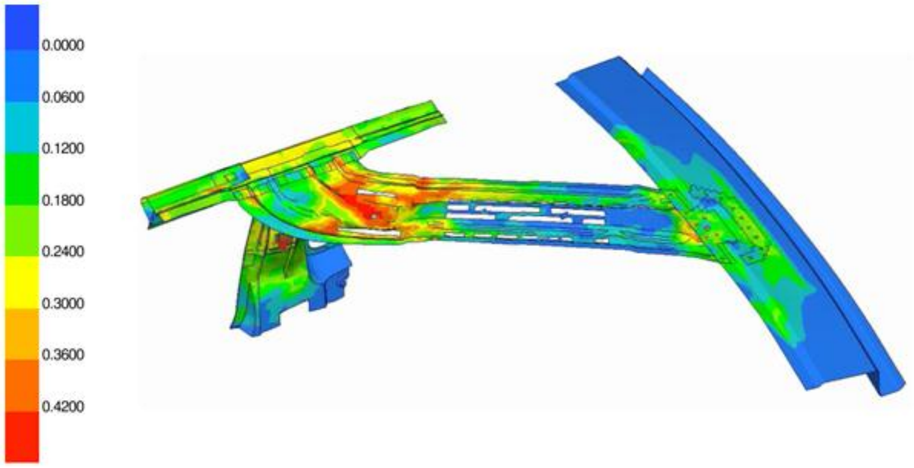

Figure 138: Graphic representation from Detail C on Figure 135, regarding displacement [mm]. (*Volkswagen Simulation Department*)

Figure 139 shows a graphical representation from the critical point on Detail D Figure 135, in which it is possible to visualize a change on the behaviour of the system. This change is connected to the rupture point, where, and according the representation from Figure 140, there is a rupture in a C-pillar spot weld as well as there is a critical deformation on some components of that area.

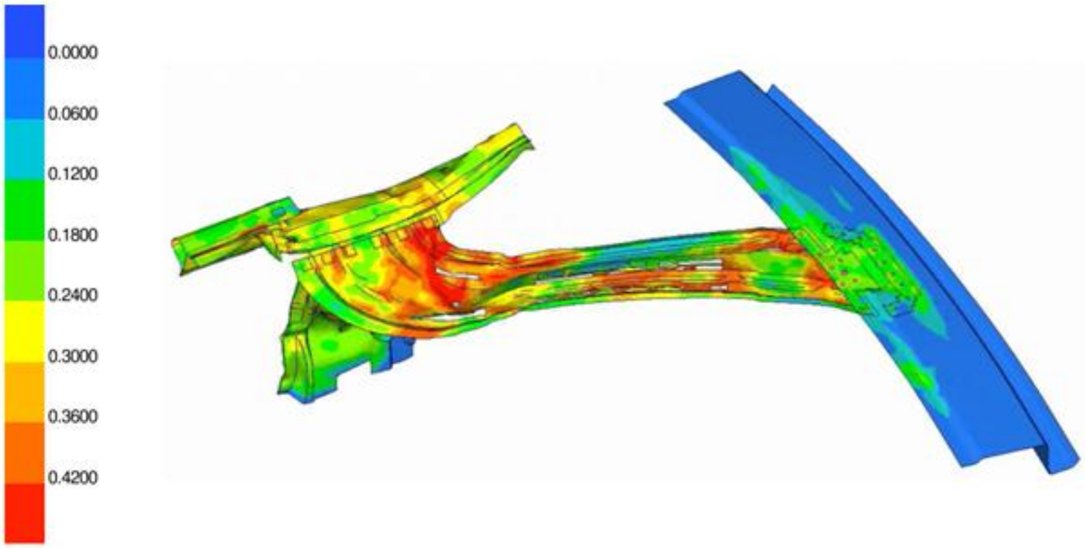

Figure 139: Graphic representation from Detail D on Figure 135, regarding displacement [mm]. (*Volkswagen Simulation Department*)

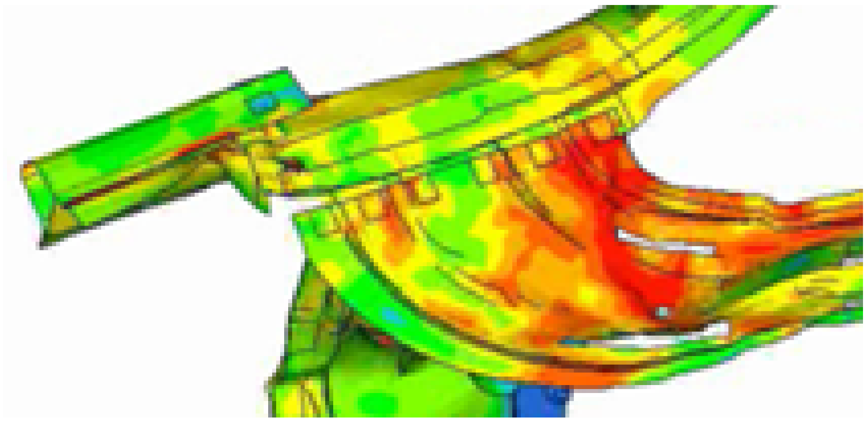

Figure 140: Rupture point on C-pillar. (*Volkswagen Simulation Department*)

At this point the D-ring fixation shows a displacement of approximately 66mm.

The same criterion was used to the different geometry / material / thickness option present on Table 9, and results are described on Table 11.

These results show that the part in study is able to perform the requested load of 18.9kN, corresponding to the regulated load from ECE R14 plus 40% of safety quotient, as standard in Volkswagen intern norms, which means that the proposed design with specified material and thickness is approved for production.

Also important to mention, the 3 “snap-back” points presented on Figure 141.

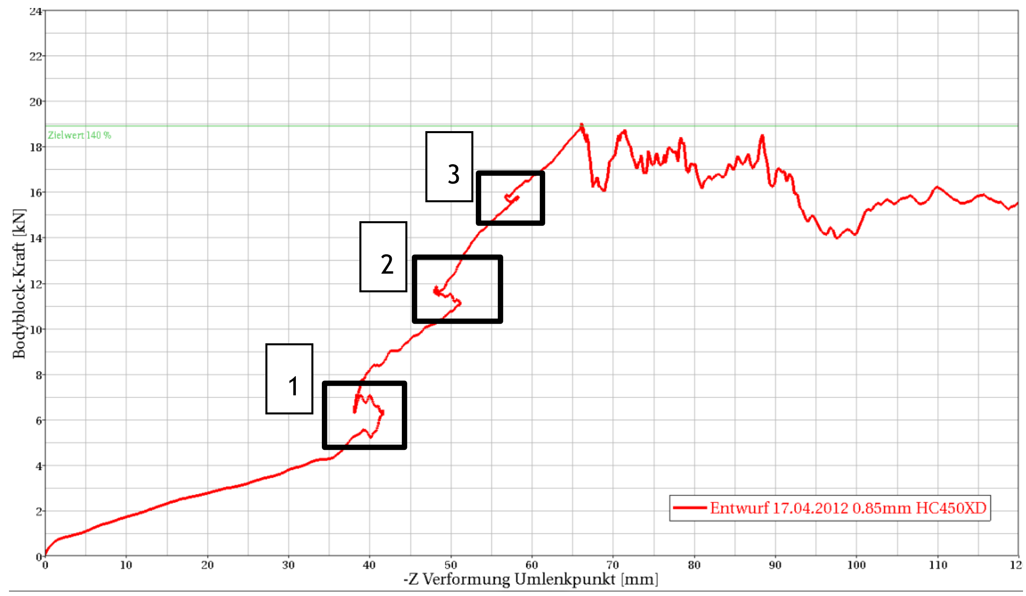

Figure 141: “Snap-back” points during simulation from the component in study with Version A, HC450XD material and 0.85mm thickness. (*Volkswagen Simulation Department*)

5.6 - Comparison of the Various Designs

For all the options presented on 5.4 – Considering Different Materials and Thicknesses were made the simulations regarding each option; in order to evaluate the component’s feasibility according to supporting the requested loads during a frontal impact. Table 11 shows the results for each variant.

Table 11: Improvement variants analyze regarding different materials and thicknesses.

Variant	Thickness [mm]	Material	Total Mass [g]	Mass Improvement [g]	Acceptance [%]
Actual part	1.00	H340LA	1917	-	140%
Version A	0.90	H340LA	1574	- 343	135%
	1.00	H340LA	1703	- 214	140%
	0.90	H420LA	1574	- 343	140%
	0.90	HC340XD	1574	- 343	140%
	0.85	HC450XD	1338	- 579	140%
	0.70	TL4225	1135	- 782	140%
Version B	0.90	H340LA	1655	- 262	135%
	1.00	H340LA	1784	- 133	140%
	0.90	H420LA	1655	- 262	140%
	0.90	HC340XD	1655	- 262	140%
	0.85	HC450XD	1419	- 498	140%
	0.70	TL4225	1216	- 701	140%

Considering the results described on Table 11, and also according Volkswagen internal, where the part should be designed in order to perform the simulation described above and resist to not only the 13.5kN requested by ECE R14 but to 140% of this load, which means 18.9kN. This internal standard refers that the part should present the rupture point above 140% of the specified load in order to be considered feasible for serial production.

Considering this norm and analyzing the results from Table 11, it is possible to visualize that two variants could be considered as feasible, due to the fact that they could only resist to a maximum load of 18.22kN. In these cases, and regarding that only the rail guide was changed in the entire simulated system, it is possible to say that it is the component in study that are not able to fulfill the requested test considering the variant Version A and B with H340LA material and 0.90mm thickness.

The remaining variants are approved to production according to virtual simulations, which means that all these options could be implemented. However it is necessary to analyze several items in order to choose the best possibility for this case, regarding:

- Mass improvement
- Costs per unit
- Investment impacts

In 5.7 – Project Feasibility, it will be analyzed choose the best improvement options in order to request to the current supplier a quotation regarding necessary investment and price per unit.

5.7 - Project Feasibility

5.7.1. – Selected Designs Associated manufacturing costs

According to the information above, it was asked to the supplier quotations for the 3 best proposals: Version A with 0.90 mm HC340XD and 0.85 mm HC450XD, due to the fact that:

- With this geometry it would be necessary a complete new tool, which means it would be also possible to change the material in order to have a better mass improvement
- Best mass improvement without using special processes or materials like TL4225, which would highly increase costs.

Version B with 0.90 mm HC420LA:

- In order to keep the actual tool only with new holes implementation reducing initial investment, if the tool is already prepared for a different thickness
- Do not use a galvanized material, so it is also not necessary to change the actual tool coating.
- Best compromise between mass improvement and final price per unit regarding material achieved with Version B.

Supplier also suggested analyzing HC420LA material with 0.9 mm considering a new tool and 1.0 mm changing the current one.

Table 12 summarizes the Gestamp quotations, including necessary tool changes and consequent investment for each case. Also the price per unit was review for each variant, where Δ represents the actual price for current component.

Table 12: Official quotation from Gestamp Portugal

Variant	Material	Thickness [mm]	Premises	Investment	Price per Unit [€]
Version A	HC450XD	0.85	New tool	High	Δ + 0.58€
Version A	HC340XD	0.9	New tool	High	Δ + 0.53€
Version B	HC420LA	0.9	New tool	High	Δ + 0.02€
Version B	HC420LA	0.9	Current tool with changes	Not feasible, the actual tool is only designed for 1.0mm thickness	
Version B	HC420LA	1.0	Current tool with changes	High	Δ + 0.02€

Analyzing Table 12, it is possible to take some considerations. New geometry request necessarily a new tool, this means a bigger investment. For those cases, also the change for a better material represents an increase in the costs per part.

Regarding the Version B, there are 2 different scenarios: first if the thickness is reduced, that requests a new tool, due to the fact that it is not prepared for a different thickness as not 1.0 mm; on the other hand if maintaining the actual 1.0 mm thickness, the improvement would be not so high as expected. However, there is also another consideration, due to the fact that increasing of the number of holes, the first and the last operation should be completely rebuilt and not only adding new punches, which means that the investment would not have a significant decrease, comparing to a new complete tool.

5.7.2. – Cost Analysis

As described in Chapter 1 product improvement process, the last stage from project phase is the project feasibility evaluation.

As premise, the improvement must be profitable 12 month after implementation. In Table 13 is possible to analyze the project feasibility taking in consideration the necessary lead time to make the new geometry implementation profitable.

Table 13: Official project feasibility according to quotation from Gestamp Portugal and necessary lead time to its profitability

Variant	Material	Thickness [mm]	Mass Reduction [g]	Amortization [years]
Version A	HC450XD	0.85	- 579	5.89
Version A	HC340XD	0.9	- 343	15.61
Version B	HC420LA	0.9	- 262	6.36
Version B	HC420LA	1.0	- 164	8.78

According to the evaluation sheet and taking in account the actual production volume from Volkswagen Sharan, the best possible scenario is the proposal 1, where the part would have a completely new geometry with HC450XD material and 0.85mm thickness as well as the biggest mass improvement with 579g less per part. This proposal would need 5.89 years to be profitable, which could not be implemented by a product improvement process, due to the fact that it does not fulfill the specified requirements.

6

Conclusions and Recommendations

6.1 - Conclusions

Fuel efficiency is nowadays a highlight and one of the top comparisons between models from different vehicles manufacturing. Despite this fact, most developed countries and insurance companies, adopted the CO_2 emissions from each model in order to calculate to their taxes calculations or insurance premium. These particular points have, for most final consumers a great impact in their decision process, when it is necessary to buy a new vehicle.

This study presents the lightweight design as great valid option, in order to reduce the total weight of a vehicle. This concept allows the possibility to improve a specific component and implementing it in a current or new serial production vehicle with low investment and cost per unit.

From the results of this project, it is possible to conclude that this kind of technology could represent approximately 30% of improvement in a sheet metal component of 1917g, which could be more considerable if applied to the entire Body structure of the vehicle.

6.2 - Recommendations

Although the results show that for this specific case, the improvement is not economically feasible, due to the benefit taken from the a best improvement of 579g it is not enough to be profitable in 12 mouth according to the necessary investment, this kind of technology is hardly recommended to use in future models, considering the possibility of a considerable in the entire Body structure.

Also important to taking in consideration for future projects, the possibility of adapt a different fixation concept, according to 2.3 – Benchmark, in order to improve the actual concept used in Volkswagen, increasing the mass reduction as well as improving the costs per vehicle.

Bibliography

Agaram, V., Xu, L., Wu, J., Kostyniuk, G., and Nusholtz, G. (2000). Comparison of Frontal Crashes in Terms of Average Acceleration. In Proceedings of the SAE 2000 World Congress, 6-9 Mar, Detroit, MI, USA, paper nr. 2000-01-0880 in SAE Technical Papers.

Ashtiani, M., Sickson, R.P., Oliver, M.L., and Kruckemeyer, W.C. (2002). Variable load limiting restraint retractor. Patent no: US6481659, 19 Nov.

Dayton Progress Corporation (2003). Stamping Basics Fundamentals & Terminology. Ohio, USA.

Economic Commission for Europe (2006). Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts Which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of These Prescriptions. Technical Report R14. Addendum 13: Regulation No. 14 Revision 5. United Nations

ESI Group. (2012). Virtual Performance Solution 2012. Paris, France.

Hesseling, R.J., Steinbuch, M., Veldpaus, F.E., and Klisch, T. (2006b). Identification and control of a vehicle restraint system. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 220.

Huang, M. (2002). Vehicle Crash Mechanics. CRC Press, USA, 1st edition.

Huston, R.L. (2001). A review of the effectiveness of seat belt systems: design and safety considerations. International Journal of Crashworthiness, 6(2).

Karlow, J.P. (1998). Variable level seatbelt energy management device. Patent no: US6019392, 1 Feb.

Kawaguchi, K., Kaneo, N., Iwamoto, T., Fukushima, M., Abe, A., and Ogawa, S. (2003). Optimized Restraint Systems for Various-Sized Rear Seat Occupants in Frontal Crash. In Proceedings of the SAE 2003 World Congress, Mar, Detroit, MI, USA, paper nr. 2003-01- 1230 in SAE Technical Papers.

Kent, R.W., Balandin, D.V., Bolotnik, N.N., Pilkey, W.D., and Purtsezov, S.V. (2007). Optimal control of restraint forces in an automobile impact. Journal of Dynamic Systems Measurement and Control, 129(4).

van der Laan (2009). Seat Belt Control From modeling to experiment. Technische Universiteit Eindhoven, 2009. Proefschrift. – ISBN-13: 978-90-386-2086-2. Eindhoven, Nederland.

Mihai, S., Pop L., Grama L. (2011). Simulation Studies on the Use of Stamping Software on Auto Parts. Fascicle of Management and Technological Engineering, Volume X (XX). Oradea, Romania.

Miller, H.J. (1996). Restraint Force Optimization for a Smart Restraint System. In Proceedings of the SAE International Congress and Exposition, 26-29 Feb, Detroit, MI, USA, paper nr. 960662 in SAE Technical Papers.

Paulitz, T.J., Blackketter, D.M., and Rink, K.K. (2006). Constant Force Restraints For Frontal Collisions. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 220(9).

Ruukki. Resistance Welding Manual. Helsinki, Finland.

Shin, H.S., Yeo, T.J., and Ha, W.P. (2007). The numerical study for the adaptive restraint system. In Proceedings of the SAE 2007 World Congress, 16-19 Apr, Detroit, MI, USA, paper nr. 2007-01-1500 in SAE Technical Papers.

Shiotani, M. and Hamaue, T. (2004). Seat belt retractor. Patent no: EP1468883 A1, 15 Apr.

Simech Simulation et Technologie (2001). Introduction to Sheet Metal Forming Processes. Paris, France.

Smithson, A., Blackadder, D., Taylor, J., Andrew, D., Joe, H., and Andrew, P. (2000). Load limiting device for a seat belt. Patent no: US6183015, 6 Feb.

Volkswagen AG. (2010). VW 01105-1. Widerstandspunktschweißen, Konstruktion, Berechnung, Unbeschichtete und beschichtete Stahlbleche. Wolfsburg, Germany.

Wood, D.P. (2003). Velocity changes, mean accelerations and displacements of some car types in frontal collisions. International Journal of Crashworthiness, 8(6).

WWS Group. An Introduction to TIG Welding. Hertfordshire, UK.

Yeh, I., Kachnowski, B., and Subbian, T. (2005). Optimization of a Vehicle Restraint System Using a Genetic Algorithm. In Proceedings of the SAE 2005 World Congress, 11-14 Apr, Detroit, MI, USA, paper nr. 2005-01-1227 in SAE Technical Papers.