

# APPLYING NEW BLOW-FORMING PROCESSES TO OBTAIN NEW STRUCTURAL COMPONENTS FOR AUTOMOTIVE INDUSTRY: A-PILLAR

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## Abstract

The aim of this project is to determine the technical viability of the bodywork manufacturing process using the blow-forming technology. Specifically, the blow-forming technology has been studied to be applied to manufacture the A-pillar. The results of using this technology reveal the following:

- Weight and CO2 reduction due to the fact that this technology makes it possible to use thinner high strength steel.
- Passengers' safety improvement.
- Improvement of the driver's sight angle as a result of the smaller section of the A-pillar.
- Reduction of manufacturing costs.
- Reduction of the number of components of the A-pillar.

During the development stage, the following results are also achieved:

- Harden material above 1.500 MPa.
- Up to 20% of A-pillar weight reduction.
- Utilization of material by 95% vs 40% of current use.
- Component number reduction.

Results suggest that the application of the blow-forming technology to manufacture the A-pillar is technically viable and complies with the geometric and manufacturing requirements.

**Key words:** *Blow-forming; Manufacturing processes; High strength steel; A-pillar.*

## 1. Introduction

Lately, the automotive industry sector is experiencing a progressive harshening of demands new models must meet. A clear example of this fact is the obligation to offer vehicles which provide greater safety for its occupants at crash tests. Other important demand is the continuous reduction of vehicle consumption, and in order to achieve it, the strategies automobile producers use include constant reduction of different components and parts weight. In order to meet these demands, which occasionally could seem contradictory, producers are looking for alternatives to materials traditionally used to design and manufacture structural components. An example of this type of materials are advanced high-strength steel, which allow to notably reduce the thickness of the parts, compared to parts designed with other types of steel, and, therefore, weight in parts with structural requirements in the bodywork.

However, the use of these types of steel entails serious difficulties. First, when using high-strength steel in traditional molding processes, such as cold forming, serious problems arise. These problems, which are not originated from the very steel's lack of ductility, are due to the magnification of the elastic recovery phenomenon, and to the pronounced wearing and constant breakages of the forming tools, which obliges to reconsider and redesign the material the formation equipment are made of.

These problems are particularly relevant in high-strength steel, higher to 1000 MPa, precisely those which most interest awake in industry for the relevant weight decrease its use would mean.

With the objective of solving these problems, in the past few years, new forming processes for steels with up to 1500 MPa of mechanical strength are being developed. Carried out in hot, so that the steel plate deforms due to the high temperature, these processes seek to exploit the characteristics of the material in its austenite phase, in which the material has a high ductility. After the hot metal forming, it is tempered to achieve martensitic structures. The tempering has the peculiarity of being carried out within the forming equipment, where it takes advantage of the low temperature of the tool, which makes the subsequent cooling, which also serves as self-tempering, remove the problem of elastic recovery. This process, called hot stamping, which as stated above, allows working with high strength steels, is used by SEAT to manufacture A and B pillars of the new SEAT Ibiza.

This article shows the results obtained from the research carried out for the design and development of the A-pillar, using high-strength steels and applying new manufacturing techniques. The research carried out has enabled assessing the use of these new technologies for the development of structural elements by hot blow-forming. The data obtained are of great use for the comparison of these technologies with those traditionally used, and facilitates decision-making process in relation to the possible use of high strength steels and hot metal forming in future development projects for vehicles of the brand.

## 2. Project Objective

This article describes the results of one of the projects SEAT has carried out, aimed to reduce air contaminant emissions from the use of its vehicles, as different European and automotive sector's environmental regulations demand. One of the possible courses of action to achieve it is the reduction of the total weight of the vehicles by the replacement of heavier by lighter components, without adversely affecting the performance of the vehicle.

This article presents the results of the project which aims to study the feasibility of implementing new forming processes, specifically the so-called hot blow-forming, for the design and manufacture of one of the structural elements of the vehicle: the A-pillar of SEAT Leon's future model. In addition to determine the technical viability of the process, the project is aimed to study the characteristics of the most appropriate material for the part's design and for the very process used for its production.

If feasible, this new form of hot metal forming would allow SEAT Technical Center (hereafter, CTS) apply this technology in other parts of the vehicle, of greater dimensions, such as the ring, which would help to achieve reductions in weight and larger emissions.

The specific objectives of the project are:

- Redesigning the A-pillar, so that it can adapt to the geometries to be obtained by the how blow-forming process.
- Selecting the materials to be used to make the piece by this procedure, while maintaining minimum requirements at 1500 MPa.
- Analyzing the process of manufacturing as a whole, detecting potential points to improve and possible redesign of the piece.
- Analyzing the requested performances: mechanical and resistance to corrosion, among others.

## 3. Justification and Expected Benefits

The expected benefits, in case the feasibility of the process is demonstrated, are listed below:

- Weight reduction and, consequently, of CO2 emissions of vehicles.
- Increase in passenger safety.

- Reduction in manufacturing costs and an improvement of the production process's impact on the environment.

The idea behind the use of this type of metal forming by hot blowing is the possibility of using high strength steels, which allows obtaining parts with high mechanical performance using a minimum of material. This implies that, in case this type of processes and materials can be used, it could translate in the reduction of both the section of the part and its weight. Other advantages that might be achieved, resulting from weight reduction on the part under research, are a reduction in CO2 emissions and an improvement in the vehicle dynamics, in the acceleration as well as in the braking, and its behavior on the road. This is due to the fact that weight reduction in the vehicle's upper area, place where the part under study is found, contributes to shift the center of gravity of the vehicle towards the ground.

On the other hand, the use of more resistant structural components would provide greater safety for the passengers of vehicles thanks to:

- Increase of the resistance of the elements mentioned above, helping to strengthen the resistance of the entire vehicle.
- Increase of the driver's field of vision, since it is possible to produce A-pillars with a smaller cross-section, meaning the least possible hindrance to the field of vision. This would reduce the blind spots originated in this area and would increase safety while driving.

Finally, it is expected that the use of a amount to manufactured by hot blow-forming will help bring about a reduction in the complexity of the manufacturing process of the vehicles, and therefore a reduction in both the manufacturing costs and the impact of the production process on the environment. This would be reflected through:

- The reduction of the number of components that are part of the A-pillar, thus getting logistical advantages, a reduction in manufacturing and handling spending, the use of fewer tools, a cheaper manufacture and the minimisation of assembly expenditure.
- The increase of the degree of better use of starting material, due to the possibility of moving from the current stamping process to a future one of shaping.

In summary, the implementation of this project is expected to reduce the weight of the A-pillar in approximately 35 per cent and reduce costs and investment while maintaining or even improving the structural behavior of the part.

## **4. Metodology and activities**

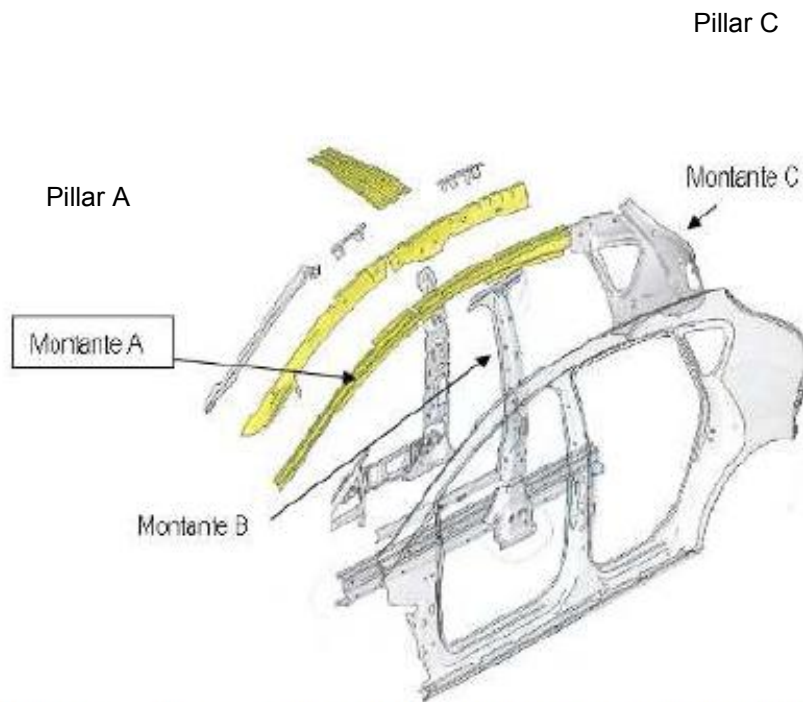
### **4.1. Antecedents**

This section explains the background and motivations that led to the approach of the use of new materials and production processes to design and manufacture the vehicle's structural elements, as the A-pillar is.

Within the body of a car there are a series of high-structural responsibility components, such as the pillars A, B, C and the sill board, which form the so-called ring.

During the development of previous projects, and mainly in those related to the development of the current SEAT Ibiza, some decisions were taken such as the elimination of the roof's central beam, with the basic goal of reducing weight, while ensuring the protection of the occupants in the event of a collision. This contributed the following benefits: reducing the complexity of production, reduction on the number of parts and less logistical costs. By eliminating the new Ibiza's main beam, some measures were taken to guarantee the proper functioning of the vehicle. However, the margins of safety regarding the side-impact were significantly reduced. This is caused by the fact that the support for the A-pillar should be extended to the C-pillar area, unlike what was done in the predecessor vehicle series, current SEAT Leon, where the upper A-pillar doesn't connect with the C-pillar. By lengthening the A-pillar, and not having an intermediate support in the B-pillar area, the bending on the zone is very high, increasing the risk of collapse during a side impact, and significantly increasing the intrusions in the upper zone of that pillar.

**Figure 1: Complete shaped ring, consisting of pillar A (highlighted in yellow, the aim of this project), pillar B and pillar C**



In view of the results in physical tests, it was decided to initiate activities that enable to ensure a better side crash performance of the upper A-pillar in future projects.

Research carried out to solve this problem reflected that in case of having an upper A-pillar made of hot stamp steel, type USIBOR 1500, a much more appropriate behavior is obtained, to increase the margins of safety in the event of side impact.

The study also considered alternatives, such as additional pieces within the A-pillar, which appeared much less efficient, both in cost and weight, than the solution based on the use of high strength steels.

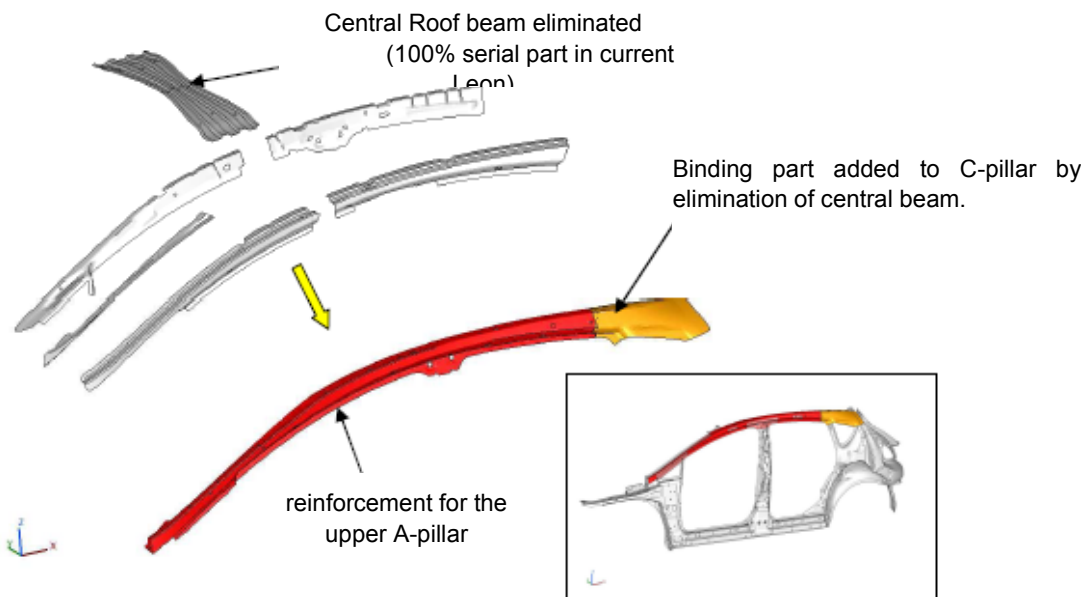
**Figure 2: Comparison of plastic deformations in the upper A-pillar during Side Crash in the new Seat Ibiza. Comparative detail of plastic deformations in the upper A-pillar in side crash for the new SEAT Ibiza**



In order to carry out the feasibility study of high strength steel forming process, the CTS Bodywork Department was requested to propose an upper A-pillar geometry, and subsequently, this geometry was introduced in a finite element model of current SEAT León to perform the necessary simulations.

Figure 3 shows the structure of the upper A-pillar ring of current SEAT Leon, and the structure developed for this study, consisting of the reinforcement for the upper A-pillar, in red color, plus the part extended to reach the C-pillar.

**Figure 3: Comparison of the parts used in previous models together with the parts developed for this project**



Change of structure in the conceptual simulation on current SEAT Leon (substitution of parts of serial model 100% by part shaped upper A-pillar + elimination of the roof's central beam).

#### 4.2. Requirements requested to the part to build

This section describes the requirements both the new part developed and the manufacturing process to obtain it must comply with.

The A-pillar is a structural component of the vehicle that has to comply with the requirements detailed below:

- Stiffness. As a piece of the bodywork's structure, it must bring the necessary rigidity as an individual part, as well as in the whole body structure.
- Crash. It must meet the requirements to guarantee the integrity of the compartment in case of accident.
- Cost. Like any other vehicle part, it is subjected to some target cost to fulfill.
- Package. Compartment Package is the space available for the occupants inside the vehicle. Due to the size of the space available to provide, logical restrictions to the shape of the part take place, since the stay of the occupants within it should be as comfortable as possible.
- Weight. As well as cost, weight is a very important parameter, constantly controlled and monitored during the development of a vehicle. As stated above, a decrease of weight automatically implies a decrease in pollutant emissions.
- Vision. Given the position of the A-pillar, located in the driver's field of vision, this part interferes in his/her side vision, especially in street curves and turns. The smaller the section of it, the wider the field of vision offered and therefore, greater safety might be expected.
- Design/Aesthetics. As a part visible in great extent, whose geometry affects and influences the color proportions of the body seen, its size and orientation is an important dimension to the designer.
- Pedestrian protection. The A-pillar is a part which a pedestrian could collide with, in case of being knocked down. That is why it is essential to avoid very jagged areas that can produce serious injuries in the event of an accident.

Concerning the manufacturing process, currently the piece is manufactured through a cold-formed microalloyed steels process of relatively low carbon content that offer elastic limits in the environment of 220 to 340 MPa in receiving state (later on, profiling increases these properties). This gives rise to production of the component through the union of up to five parts, which in total weigh 12.2 kg/car. An alternative solution, of which SEAT has already some experience in the new Ibiza, would be making this part using hot stamping and the process is reduced to only three parts that weigh 8.4 kg/car.

An even more demanding option raised in this project, since it is estimated that it could be achieved with the blow-forming technology: to design the entire part as a single component, reducing its final weight to only 7.9 kg/car.

### **4.3. Hot stamping process**

The hot stamping process is a process patented by the company Linde-Wieman, who participates as outsourced company in the project. The process consists of the steps described below. First, a pre-form of the part is obtained through traditional cold forming/shaping. Subsequently, the profile is closed, and a hole and a compartment are made by welding. Finally, through a process of deformation by blow-forming, which is the real novelty of the project, the part takes on its definitive form.

The blow-forming processes fall within the category of fluid molding, being the most characteristic the hydroforming, mainly applied to cold forming processes. This type of processes has the advantage of producing a uniform pressure, on the contrary to classic stamping processes that can produce local concentrations of efforts. On the other hand, since it is possible to control at will the pressure applied to a temperature-time sequence, it is possible to achieve complex parts and thicknesses, at the same time variable.

In the case discussed here, once heated the part, either in a conventional oven or through induction, it is inserted in the forming matrix, where air to 300 bars of pressure is blown. Once the form is obtained, the part is cooled in water, while it is still inside the die, going from 900 to 40 °C in 10 seconds. Finally, the ends are cut off and the holes required are made by laser or any other procedure to define.

After the first meetings of SEAT and Linde-Wieman, it was clear that a committed solution between the current geometry of the A-pillar in the new SEAT León and the apparent possibilities of the blow-forming process according to Linde-Wieman's own experience had to be sought.

Therefore, the first stages of the project focus on making the needs of SEAT converge with the possibilities of the process. For this, CTS provides at this stage a new methodology for innovation, which will allow, at the Concept stage, the creation of a parameterized 3D mathematical geometry model. With the mathematical model, developed from an initial external surface corresponding to an early stage in the development of the design, a valid result is obtained to be able to initiate, the simulations, among other activities. After successive iterations between CTS and Linde-Wieman, and agreement was reached on the final geometry to manufacture and the material to use. Regarding the material, it is clear that for this type of technology a steel of easy temperability has to be chosen. However, this effect is not desirable if there are intermediate welding operations. Likewise, the hardenability is traditionally achieved alloying, which is usually detrimental to the material's very ductility in cold. Concerning this, there is a tendency to use microalloyed steels with boron, which seems to be a solution that can be combined in this process.

The second stage of the process, welding, requires a steel of easy weldability. This requirement goes against the requirement of high hardenability, necessary in the final stage, and therefore it is necessary to find a compromise solution. As a result of the characteristics of the materials, part to develop and process to be used, two steels microalloyed with boron are initially chosen for the project: 22MnB5 and 27MnB5. In both cases, it was decided to test with and without the coating supplied by the manufacturer. Due to the fact that steel presents hardenability, it is necessary to choose a welding process that, in addition to being fast enough to not affect productivity, does not prompt steel cracking. However, it should be mentioned that although martensitic structures produce in welding, since the part is heated later for the final blow-molding, the microstructure disappears. Thus, the mere appearance of martensite should not be considered a problem, but the weakening of the material should, so that it can crack while cooling it or in subsequent manipulations, before the blow-forming.

The final microstructure, and therefore the mechanical properties are going to depend almost exclusively on the tempering after the blow-forming process. The tempering, once steel is fixed, will depend on the

speed of cooling. In principle, a steel as the USIBOR1500 requires tempering speeds of nearly 70-80 °K/s, what theoretically the blow-forming process can seemingly accomplish, although this also depends on the thickness of the steel. In the case of pieces with curvatures and slight section variations, it is possible that not all the piece's parts cool equally, and therefore they have different mechanical properties. Hence, how homogeneous is the microstructure and the very mechanical properties must be assessed, and act accordingly.

Once the part is built, the next step is to determine if all the requirements requested for the A-pillar listed above have been met. Particularly important are the requirements to impact. Here it is worth mentioning that even though the part might not have a complete micro-structural homogeneity, it doesn't mean it has to be ruled out, as long as it meets the mechanical requirements. Furthermore, if it has certain micro-structural heterogeneities, these can be included in the simulation stage and redesigned according to them.

#### **4.4. Introduced innovation and applied technologies**

Technological innovation of the project lies mainly in:

- Applied technology. The technology is used for shaping with hardening by blow-forming, to produce an A-pillar.
- Development of a new structural element. An A-pillar which allows subsequent integration into the vehicle's structure is developed, in response to the inherent limitations of the technology used and offering identical or better performances compared to the existing ones, so that the safety of the vehicle is not altered.
- The viability of its industrialization. The development of the A-pillar through the use of shaping technology with hardening by blow-forming must face the challenges of the industrialization of this technology in a way that the prototypes to develop may be viable in the future, in the context of its industrialization.
- The application of new software tools for the design stage and calculation: the virtual technical model.

Following, the detailed description of the innovations the project provides.

##### **4.4.1. Shaping Technology with hardening by blow-forming**

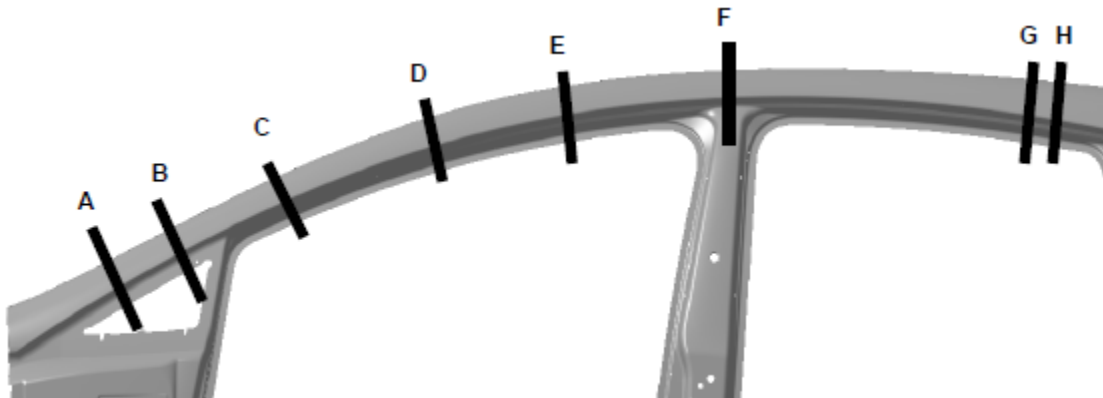
The shaping technology with hardening by blow-forming is characterized by exploiting to the maximum the advantages of each of the processes related:

1. From shaping. The advantages of this process are:
  - Use of closed sections.
  - Transforming operations integrated into the same shaping process (pre-stamping and post-stamping).
  - Variable design of the parts (e.g. the length of the profile can be varied depending on the requirements without the need of new tooling).
  - Controlled cost of tooling versus equivalent cost in stamping process.
  - Minimal waste of material.
2. From hardening by blow-forming. Its advantages are:
  - Optimized design of the process: Integration of all operations on the blow-forming shaping line.
  - Section adaptable to the contour: Possibility to vary the section on an ongoing basis along the part.
  - Material hardened above the 1400 MPa based on material from 500 MPa.
  - Excellent energy absorption to face impacts.

The technology is already patented by Linde-Wiemann, and it is part of the various processes available to the company for the hardening of profiled parts. However, despite the fact that this technology is currently being applied in the automotive industry in other parts, such as bumpers, it is still pending to assess their feasibility in the development of other components for the automotive sector, as the A-pillar, mainly due to the different geometries between some components and other and that they therefore require of its on research, in order to determine whether the technology can be adopted for this type of parts.

Figure 4 shows the comparison of sections proposed by Linde Wiemann versus the original concept of SEAT Technical Center.

**Figure 4: Sections used in the analysis of A-pillar**

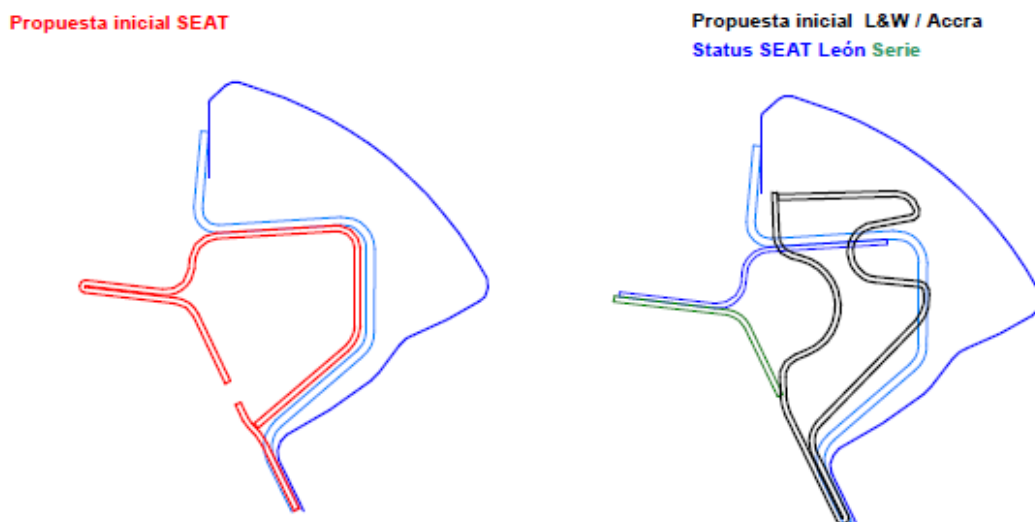


Introducing the longitudinal grooves in the profile reinforcement by Linde Wiemann, is due to limitations in the productive process of the part, which only admits a maximum of 30% lengthening in the material during the manufacturing process. Since there are sections radically different in the front and back sections of the formed pillar, it is necessary to introduce these longitudinal folds in order to ensure the industrial feasibility of the part.

However, the sections resulting from the industrially viable proposal involve an unlikely functional geometry in the front part of the upper A-pillar, especially by requirements of the Offset shock. This raises the need to build a finite element model to reflect the design of the new SEAT Leon, because the geometry of this reinforcement, the A-pillar, is greatly conditioned by the design of the vehicle itself.

L&W/Accra initial proposal, Status SEAT Leon series.

**Figure 5: Comparison of two alternatives for the C-C section**



To meet this need for calculation, it was suggested to build a new working tool: The Virtual Technical Model.

#### 4.4.2. Virtual Technical Model

As a new methodology for innovation, in the development of the new Leon, CTS has developed a tool that allows the creation of a parameterized 3D mathematical geometry model in the Concept stage, where from a initial external surface (skin), corresponding to an early stage of the development of the design, a valid result is obtained, to be able to initiate the simulation, among other activities.



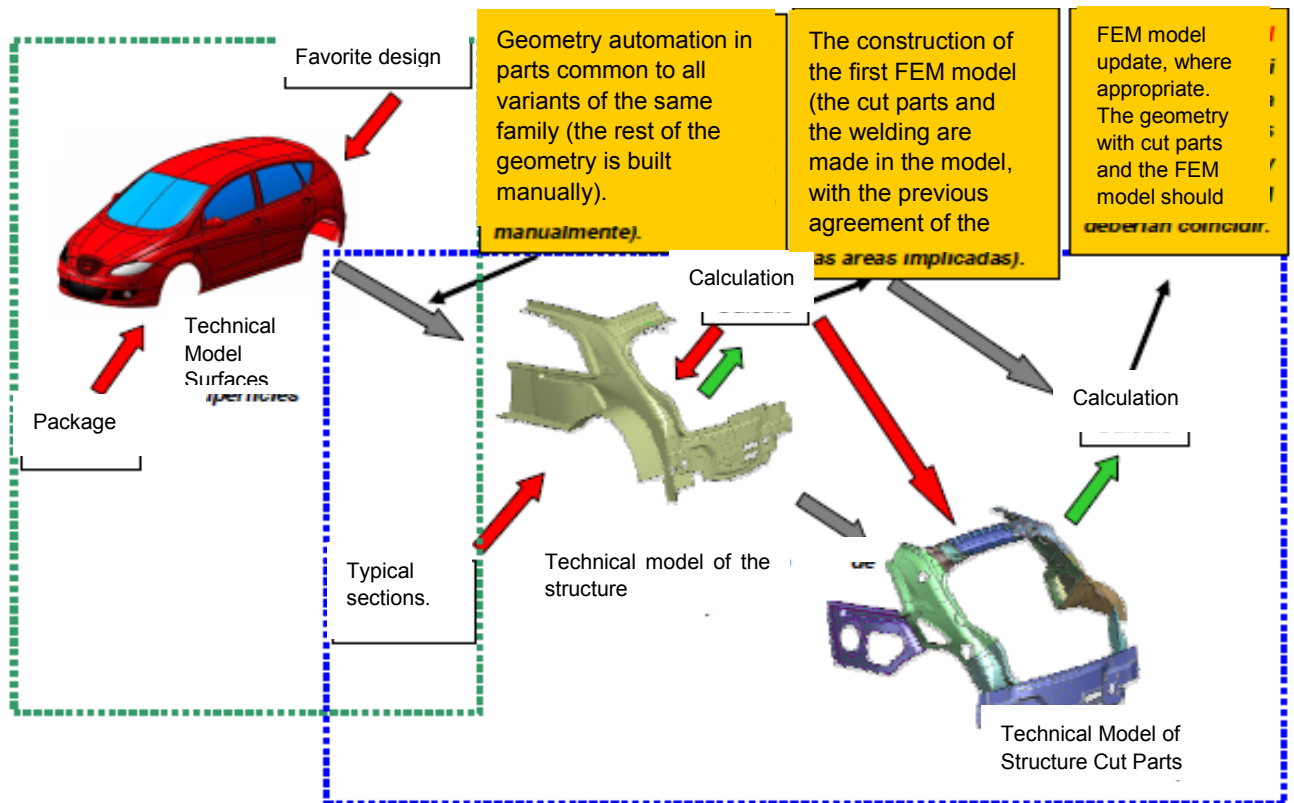
For it, initial reports that accompany the mentioned Design are taken from:

- Package and Ergonomics. These guarantee the desired architecture, the dimensions which secure the comfort and driving space.
- Technical and technological concepts. These guarantee the feasibility of implementation of the previous paragraph, Package, using the so-called "typical sections" for it.
- Feasibility Studies. This activity is the main source of information for the development of the technical model, since it guides during its construction and joins the previous sources.

The process is the following:

1. It starts from a 'favorite' design model (in these phases there are often four or more design alternatives).
2. The information for this model is minimally adapted/transformed through the application of basic technical concepts.
3. From this moment on the generation of the geometry of the technical model really starts, developing the different parts of it separately (see Figure 6).

**Figure 6: Technical Model creation process**

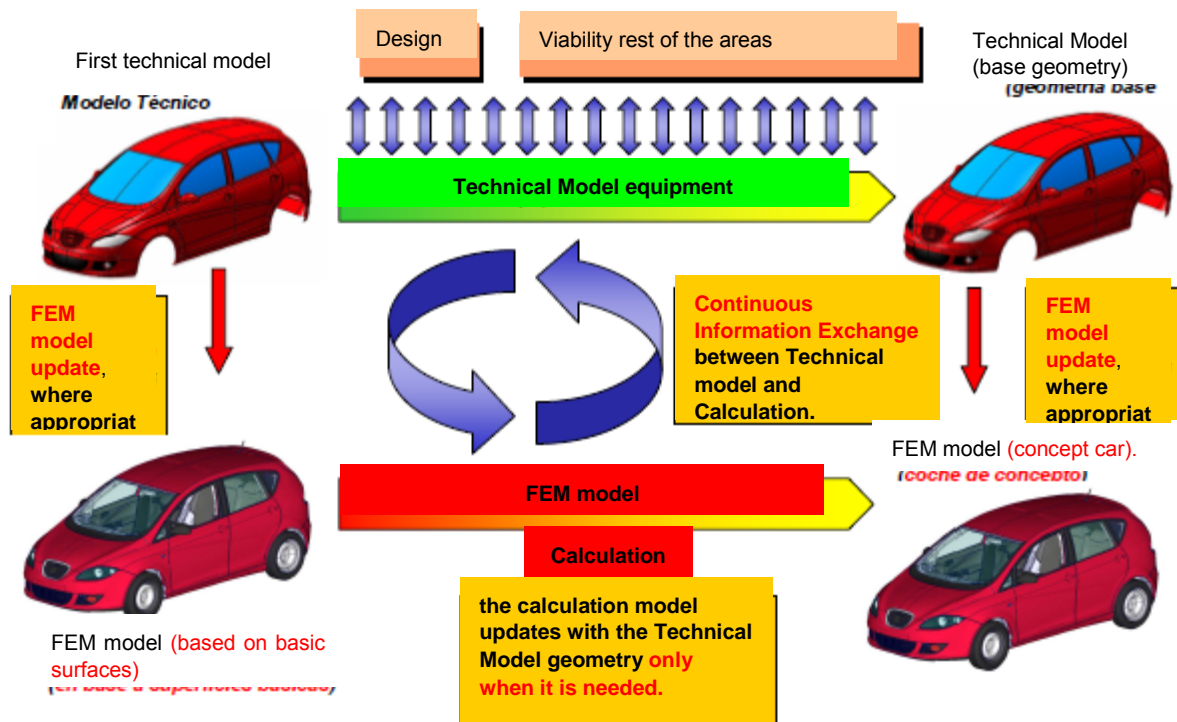


A brief description of the process is provided below:

- It starts with a parameterization of common areas, getting a general basic surface. This surface is divided into segments in response to parameters of manufacturability, assembly, and concepts of unions, among others.
- Basic surfaces are used to produce the first simulations of the different states and load tests.
- Simulation feedback also feed the Technical Model geometry, as the design continues.

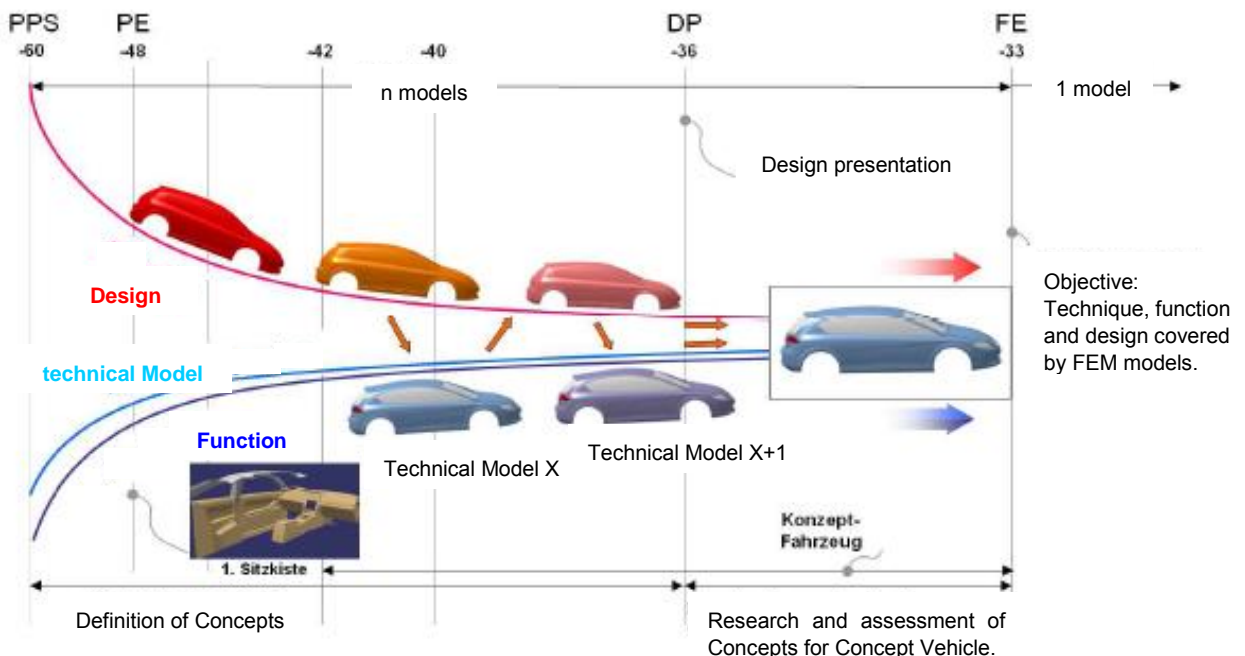
New information on the design (surfaces) appears, so also the technical model must be updated. Thanks to this, the construction of the geometries is associated with the design, updates to the model are relatively quick to make, enabling us to provide a very satisfactory response regarding the time of development (see Figure 7).

**Figure 7: Steps of the process carried out**



Two or three rounds of calculation are normally carried out. In the same period of time, the design has matured, coming close to its final definition or freezing. One of the advantages of this process is to obtain, at times, at a very early stage, the data to build a Concept Vehicle, first functioning prototype, almost a 100% representation of the design and technical features. (see Figure 8)

**Figure 8: Design Phase Update**



Finally, a list of the main lines of action followed during the development of the project to check if the parts developed from the previously described technology are technically and economically viable:

- Design, simulation and optimization of the new design. Prototype construction.
- Characterization of material and part's properties.
- Experimental tests and validation.

The results described below are obtained from these working lines.

## **5. Results**

### ***5.1. Produceable Geometry Design***

This phase of the project leads to results such as a geometry for the A-pillar to manufacture through the cold profiling process, followed by welding for profile closure and blow-forming. This initial stage is iterant until apparently undamaged parts are obtained. However, simulations are carried out to shorten the number of tests and come as close as possible to an undamaged part in the first tests. For simulations, the methodology of technical model innovation developed by SEAT is used. Subsequently, comes the making of the prototypes, both of the forming tools, and the parts themselves.

### ***5.2. Material and Part Properties Characterization***

Once the apparently undamaged parts are obtained, a mechanical study of them is carried out. In order to do this, we proceed to evaluate the microstructures obtained through the corresponding metallography tests. In addition, the mechanical properties are studied through localized evaluation using hardness and traction tests. This is done on all the undamaged parts, and according a forming condition chart to be considered later. In this sense, it is necessary to evaluate especially how the blow-forming parameters affect the microstructure, and particularly, the initial temperature, the blowing pressure, the severity of the tempering tool, either air or water and the molding temperature, and the type of steel chosen.

The results obtained may eventually feed the design phase back, to adjust it further on. This stage also includes characterization of the material's state of reception, to feed the first designs, as well as the dimensional verification of the component manufactured.

### ***5.3. Experimental tests and validation experimental***

Finally, the part's service performance is evaluated, so that it meets the stringent criteria for the passenger compartment protection, by carrying out various tests. This way, in case of collisions, the deformation of the compartment must guarantee the safety of passengers and it must happen in a slow, gradual way, giving time for the airbags to activate.

The results are parts that meet the specified technical requirements for all the tests on the A-pillar, both in safety and manufacturing process.

The feasibility study indicates that it is possible to design, develop and manufacture parts using blow-forming technology and high strength steels. Given the characteristics of the manufacturing process, the costs associated with this process are higher than those of the manufacturing process using conventional materials of lower performance. For this reason, the feasibility study mainly concludes that this type of materials and technologies are economically viable, provided that it is intended for mid to high-end vehicles, where the target client shows readiness to assume a slight additional cost if they perceive that the product has better features and performance, regarding visibility, safety, comfort, fuel consumption and environmental respect, in relation to competition.

## **6. Conclusions**

Blow-forming technology could allow the use of high strength steel during the design of structural parts of vehicles. The introduction of these materials offers significant advantages to manufacturers, since they enable reducing cost, material and logistics, while it facilitates the design and manufacture of vehicles with greater performances related to the consumption of fuel, safety and comfort.

The present article describes the activities of a project, and the results obtained during it, which are aimed to determine the feasibility of introducing a blow-forming process for the manufacturing of a part, the A-pillar. The results obtained suggest that the parts obtained are technically feasible and that the performances obtained are better than those of parts made with conventional materials. In addition, the feasibility research carried out concluded that this type of processes and materials can be used for premium vehicles with better performances, where the client shows availability to bear the costs of a vehicle with superior characteristics to those of the competition.

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