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## Abstract

This article describes the development of the Velaro[2] family from Siemens, starting with the first high-speed trainset in Europe with distributed traction, the ICE 3[1] of Deutsche Bahn AG. It explains how its on-going development caters to the customers' requirements, how it is organized and how this application-oriented work process has influenced development of the fourth generation of the Velaro family. The article closes with a brief overview of the Velaro D project – the latest generation of interoperable multi-system trains for Europe to be ordered by Deutsche Bahn AG.

## 1 Development basis and projects

### 1.1 ICE 3 – the basis for high-speed trainsets with distributed traction

After having made positive commercial experiences with its first generation of power car-hauled ICE trains, Deutsche Bahn AG decided in 1993–1994 to pursue a revolutionary further development of rolling stock in the high-speed rail sector. From then on, nothing would stop the abandonment of the power car concept in favor of a trainset with distributed traction. The relevant contracts between Deutsche Bahn AG and the manufacturers' consortium of Siemens and AEG were concluded in 1995. This was followed by a very demanding period of development and design, during which the technical design of ICE 3 took shape. There was no lack of challenges. They called for the development of new power bogies and trailing bogies with the first-ever integration of eddy-current brakes, an air-supported climate control system, a new control system with sophisticated diagnostic functions, and the realization of the ICE 3 in two versions: one as national single-system trainset and one as internationally operable multi-system trainset. These activities were paralleled by an intensive design process involving a mock-up of 1½ cars each of the standard ICE 3 and tilting ICE T trains, which were then presented in Poing near Munich in 1995 *(Fig. 1)*. It was during this process that the official Corporate Design for future ICE service was fully established.

The first trainsets entered revenue service on time for the opening of the World's Fair EXPO 2000 in Hanover, Germany. Since then, well over 200 million kilometers have been traveled by the total of 67 of these ICE 3 trains.

Within a decade, high-speed travel in Germany witnessed the introduction of the ICE 1 as an extended train of 12 passenger cars and two power cars, its subsequent development as the so-called ICE 2 half-train with 6 cars and a driving trailer and the capability to be operated as a multi-section train and, finally, its current state of development as ICE 3 with distributed traction. Thanks to the ICE 3's powerful design, its ability to climb grades as steep as 40‰ and its high braking performance, the cost-optimized alignment of high-speed lines, such as the new Cologne–Frankfurt/Main route, were soon a reality. Today, the ICE 3 is regarded as the flagship for the implementation of high-speed trainsets with distributed traction. The major benefits of this concept – apart from a better distribution of the masses in the trainset and the low adhesion coefficient utilization – lie especially in the larger useable floor area. The operator can use this to transport greater numbers of passengers while maintaining the high comfort of the single-deck concept. A single deck push-pull concept is does not come close to this in terms of capacity. Only a bi-level version offers comparable seating capacities, but with far less comfort.

### 1.2 The step from ICE 3 to Velaro Spain

When the Spanish railway company RENFE issued its major invitation to tender for high-speed trains in 2001, Siemens decided to offer its own further development of the ICE 3 concept and discontinue its involvement in the ICE work group (ARGE). The trade name Velaro was cho-

[1] ICE® is a registered trademark of the Deutsche Bahn AG.

[2] Velaro® is a registered trademark of Siemens AG.

Fig. 1: ICE 3 and ICE T mockups in Poing in 1995

sen for this Spanish vehicle. In an initial award round, Siemens succeeded in winning an order for 16 trainsets, which was later expanded by ten trains.

For Siemens, the separation from the ARGE ICE signified, on the one hand, a general reworking of the trainset since the interim publication of the Technical Specifications for Interoperability (TSI) and the further development of standards, such as in the field of fire protection, posed new and somewhat more complex challenges, and entailed; on the other hand, the new design of formerly non-Siemens parts. Then the customer RENFE came with additional requirements for an operating speed of 350 km/h and the idea of a three-class passenger system with sophisticated catering concepts that led to the development of more complex interior furnishing variants. What's more, the refined interior ambience known from the ICE 3 was to be enhanced even further. After a long project phase, the Velaro E trainsets were commissioned and have been operating in passenger service for RENFE since early 2008. Train service between Madrid and Barcelona has been very successful, with the trains achieving an average utilization of more than 75 %. As a result, flight traffic between the cities has dropped off drastically. In the first year of operation, the market share of the railway more than quadrupled in this respect from 11.8 % to more than 48 %! The Velaro trainsets are particularly reliable: Averaged over one year of operation, they traveled more than 600,000 kilometers between two technically-related delays of more than ten minutes. According to statements by RENFE, the punctuality of the Velaro trainsets was 99.18 % in the first year of service and includes all delays that can be caused by infrastructural, operating and technical problems.

### 1.3 The further Velaro projects

The Spanish project was followed up by two further successes in the marketing of Velaro. In 2006, Siemens, together with a local Chinese partner, received a contract

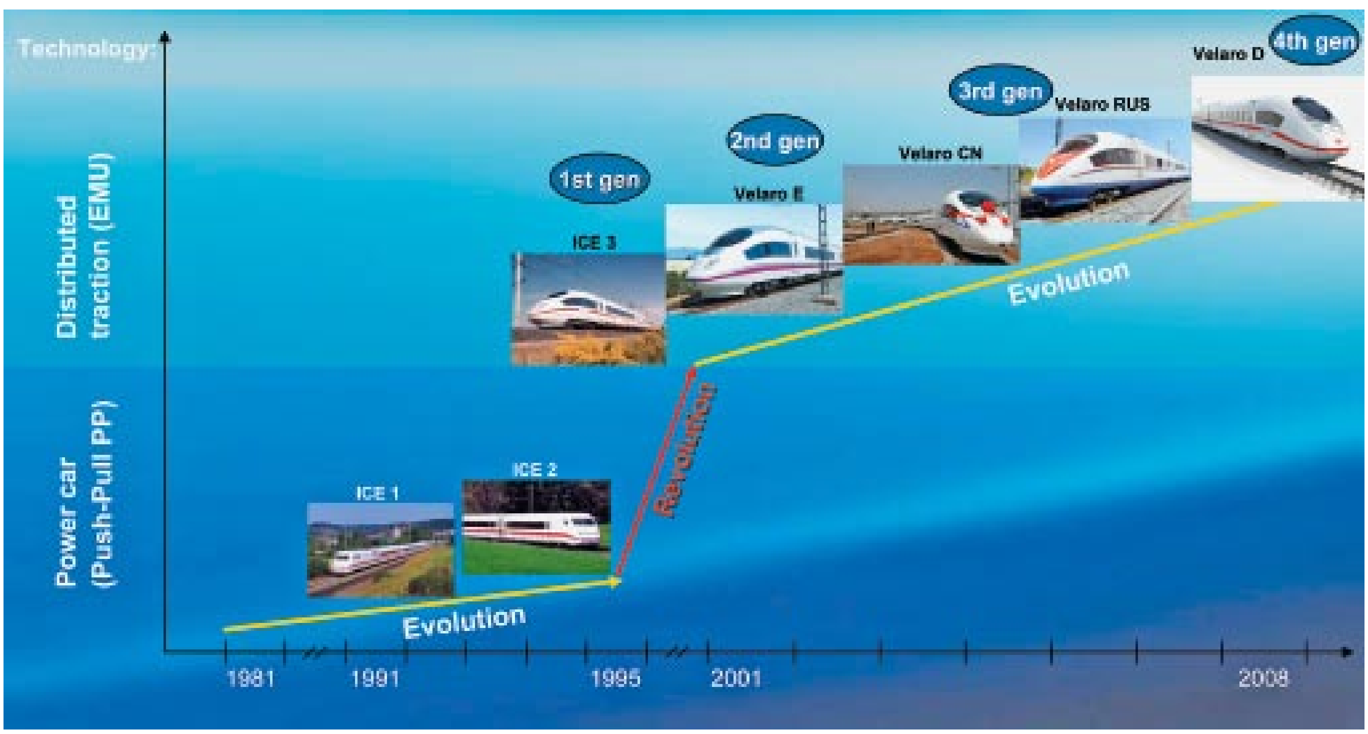


Fig. 2: Development of the Velaro family

for the delivery of 60 high-speed trainsets. The special challenges of this order consisted in the largely local production of the trains and the widening of the car body by approx. 300 mm in order to accommodate a 2 + 3 seat arrangement in the passenger area. The latter enabled the 200-m-long Velaro CRH 3 to carry more than 600 passengers. The vehicle width is one of the optimization parameters of the Velaro family *(Fig. 2)* allowing operators to achieve optimal capacity and therefore profitability.

The second marketing success came when, after a joint advance project to clarify the technical requirements for a high-speed train system for operation in Russia, Russian Railways RZD also placed an order with Siemens for Velaro trainsets. Similarly to the trains in China, these were also built using the wide version of the car body. However, the reason for this consisted in creating space to house the necessary thermal insulation against low ambient temperatures. Furthermore, it was necessary to adopt a variant of the 1520 mm broad-gauge bogie and to rearrange the air intakes and ducting to prevent snow from being sucked into the vehicle. The first ten-car Velaro RUS trains have been undergoing test and certification runs in Russia since early 2009.

Another indicator of the success of the Velaro family is represented by this year's order by the Chinese Ministry of Railways to the Chinese partner of Siemens for the construction of more than 100 sixteen-car Velaro trainsets. Siemens is participating in this order with the delivery of key components.

In all, this means that nearly 400 Velaro trainsets will be underway in a wide variety of climatic zones and infrastructures – with the majority of them traveling well over 500,000 kilometers per year.

## 2 Motivation for a platform development

The described number of different projects with their varying requirements makes three things obvious. Firstly, it becomes clear that national requirements in terms of infrastructure, network access criteria, national standards and certification requirements inevitably make any standardization or uniformity of the trainsets more difficult. Secondly, the train operators are fully justified in expecting to receive a vehicle built to their specific requirements; of course, this applies particularly to high-speed rail travel which is usually seen and marketed at a national level as a premium product.

Thirdly, however, it must also be clear that, apart from higher costs, every new concept or design also involves a higher level of technical risk – at least in comparison to long proven concepts.

But, in the end, these general conditions also motivate the manufacturer to meet the existing requirements in the best possible manner in order to develop a reliable and attractive product for his customers. Such a product with low life cycle costs will enable them to hold their own against other transportation service providers and rival companies and to earn a profit in the process.

### 2.1 Customer requirements

An analysis of the requirements placed on the product by various markets is of decisive significance when it comes to developing a market-oriented product. The requirements shown in the graphic below *(Fig. 3)* were found to be decisively important for the ongoing further development of the Velaro platform and were therefore consistently integrated into the objectives of the platform development. Continuous contact with the customers ensures that a constant adjustment of the various important target dimensions is always possible.

Some of them gain in significance, such as requirements which are associated with global warming, and some lose significance again in time.


**Fig. 3: Target dimensions for the development of the Velaro platform**

A general trend of recent years lies in the greatly increased significance of an analysis of the overall costs caused by a vehicle throughout its service life. This analysis results in the definition of sub-targets such as a noticeably improved energy balance, the development of components and systems with very high reliability rates, and the development of optimized maintenance and repair systems.

All of these demands, starting from the target matrix shown on the train level, were consistently integrated into the development of the various skilled subsystems and services, and the results are being pursued systematically. The objectives are adjusted at regular intervals depending on the insights which are gained from the markets and particularly from the customers.

### 2.2 Course of action in the development of Velaro

A fundamental analysis of the market for high-speed trains was conducted in the second half of the year 2006. In addition to the knowledge gained from customer contact data in current projects in Germany, Spain, China and Russia, development work incorporated the further developed standards, including the TSI, infrastructural situations and the information about plans and construction of new high-speed lines and expected volumes of traffic.

This subsequently led in early 2007 to the formation of a team of experienced specialists that was commissioned to carry out the further development of the successful Velaro family. The content and objective of the development contract consisted in further improvement of good solutions based on experience with previous projects and in further development of aspects offering potential for improvement. The team was guided in this case by the need to reach the target dimensions that had been set in the goal-setting matrix while complying with the total costs system. This means that a design solution is not good merely because it can be realized in a cost-effective manner; instead, it can only be defined as “good” when it can be realized in a cost-effective manner, can be maintained easily and swiftly, and is extremely reliable, energy efficient, and recyclable in an environmentally compatible way. Lastly, an optimized design for the operator is only found when all the costs incurred over the assumed 30-year life cycle are considered and proposed solutions stand up against them.

The above-mentioned development team was formed from all disciplines of engineering, from project and product management as well as from controlling and procurement and firmly anchored within the organization. In the initial phase, a detailed analysis of the competition was performed by experts from the benchmark team which also put fundamental concepts of the Velaro to the test. The results showed indications of possible development potential for the Velaro platform, but fundamentally confirmed that the concept of the self-contained unit with distributed traction was the best for meeting the high demands for seating capacity and for flexible design of the interior furnishings in high-speed rail service. In view of this fact, there was no need to make sweeping conceptual changes at the risk of diminishing reliability parameters. On the contrary, it was now possible to concentrate on the evolutionary further development of the systems.

Consequently, from the initial ICE 3 to the subsequent projects Velaro Spain and Velaro China, it is already possible to observe a noticeable drop in the failure rates from the start of operation. The latest reliability parameters from Spain show that the Velaro currently covers a distance of approximately 600,000 km between two delays of more than ten minutes. Similar observations can be made in China, where the trains have been providing very successful and fault-free service since the 2008 Summer Olympic Games.

Even though Siemens is clearly further advanced in its development of the Velaro compared to other trainsets with distributed traction, it would be rash to believe that its work has already been completed. Consequently, several focal points of the further development work on the Velaro platform are described below.

## 3 Velaro – the fourth generation

### 3.1 Overall concept as a multi-system trainset

The underlying requirement behind the work on the Velaro platform was and is the concept of a trainset:

- as a self-contained unit, permanently coupled and suitable for double-running operation,
- as a 7- to 16-car variant,
- as a vehicle with up to four-system capability (15 kV AC, 25 kV AC, 1.5 kV DC, 3 kV DC),
- as a train for European-wide and cross-border service,
- as a unit with at least 500 seats,
- with maximum speeds ranging from 320 to 360 km/h, and
- to carry two persons per square meter of standing space.

These requirements mean, for instance, that the train must be able to accommodate 750 persons, each weighing 80 kg. Although not every operator utilizes this potential, the vehicle is, however, capable of handling peak loads in economic operation – a factor that is not to be underestimated in the feasibility study.

### 3.2 Further development of the end car, front section and nose shell concepts

Probably the most noticeable change in the transition to the new generation of the Velaro family is the remodeling of the end car. The bodyshell structure of the front section was redesigned, a further developed nose shell was created, and the concept of the interior was revised.

Due to the ever higher requirements for TSI in the field of crashworthiness, it was necessary to redesign the original bodyshell concept of the ICE 3. The previous bodyshell design of the front section based on bent aluminum profiles in ribbed frame construction was discarded in favor of an aluminum lattice structure as the load-bearing element. In this case, separating the function of the transmission of forces exerted by the front end frame into the aluminum tubes of the end car from the function of styling made it possible to adopt an easy-to-make and more easy-to-repair solution *(Fig. 4)*.

The shape of the new end car, which is consciously oriented to the well-known and attractive shape of the Velaro front section, is obtained using large formed sections which are attached to the load-bearing structure.

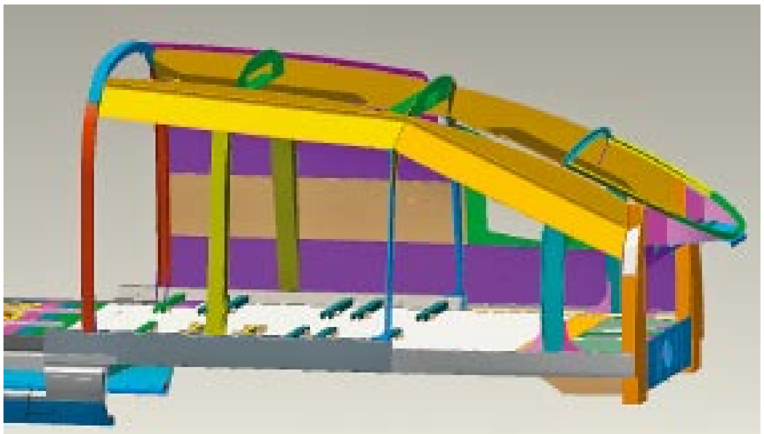

**Fig. 4:** **Redesigned structure of the front section and the first unit in production**

The front section framework of the bodyshell, consisting of A posts and parapet beams, is made with higher placed parapet beams to be able to cope with the crash obstacles defined by the TSI better than before. A crash module made of steel, which was developed and tested in the course of developing the Desiro ML platform (the Siemens platform for regional trains), is mounted to this front section framework. Apart from its ability to absorb the crash energy through deformation, it also offers anti-climbing protection. In interaction with the front coupling and its energy-absorbing element, the crash cases defined in the TSI are dealt with safely *(Fig. 5)*.

The familiar design in the form of a nose shell is mounted on the front section framework of the bodyshell, thereby finishing the form of the front section, providing a cover for the coupler and crash elements, and simultaneously serving as a support structure for the functions of the coupler doors, signal lights and horn *(Fig. 6)*.

In the course of the platform work, definite improvements were introduced which largely point in the direction of increased reliability and noticeably reduced maintenance costs. Horizontal division of the coupler doors combined with a sophisticated arrangement of the hinges made it possible to ensure unrestricted mobility of the front coupler for operation in double running without the telescoping ability that was previously required. Thus, complicated mechanisms for extending and locking the coupler or for retracting parts of the nose fairing were no longer necessary. Besides the increased reliability of this design, the lower spare part costs for the coupler must be stated as an important argument in favor of the new solution.

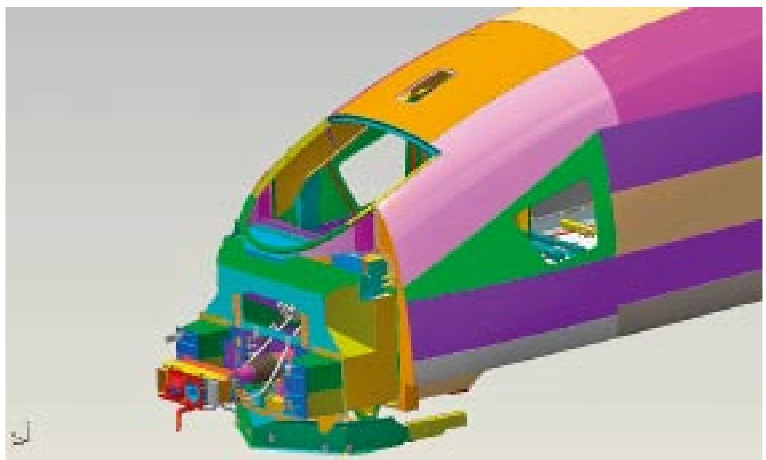

**Fig. 5:** **Crashworthy structure and front coupler**

This is also the direction that is followed by new developments of the signal headlights, which are produced completely using LED technology. It was also possible

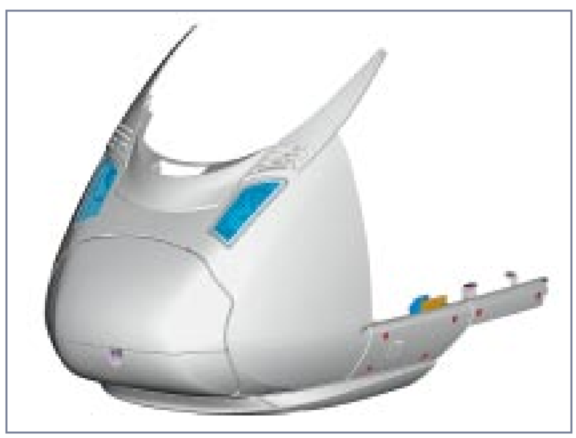

**Fig. 6:** **Newly designed nose shell with coupler doors and headlights**

Fig. 7: Aerodynamically optimized roof section

to develop an LED solution in conformity with standards for the headlights, which had previously used halogen lamp technology. This solution will provide a significantly longer service life with lower heat development and higher luminous flux. In addition, the headlight has been built so that the failure of a single LED does not mean that the entire headlight will fail.

In this connection, aspects that are relevant for maintenance, such as adjustability and interchangeability, have also been noticeably improved. Very often, added maintenance costs are now due to minor factors. For instance, the thickness of the glass headlight covers has been increased because there are larger and heavier birds in Asia than in Europe.

Also for maintenance reasons, the bottom-mounted spoilers are now made of several parts, so that the damage caused by collision with small animals and game is minimized and only that part which is damaged has to be replaced.

### 3.3 Further development of the aerodynamics

Within the context of the intensive tests that led to improved energy efficiency of the Velaro, a separate working group was set up for the important aerodynamics package. Based on the modeling of previous Velaro trainsets and subsequent simulations, various constructive measures were developed and tested using simulation technology, then developed further and simulated again, etc. In order to validate these measures, elements such as the cladding of the intercar gangways was constructed, mounted on a Velaro, tested and subjected to measurements.

All in all, this resulted in changes to a lot of details in the new generation of the Velaro trainsets and in significant aerodynamic improvements. This is most recognizable from the elevated roof section of the intermediate cars, which starts on the end cars *(Fig. 7)*.

This raised roof integrates the pantographs, high-voltage equipment, heating, ventilation and air-conditioning systems, optional braking resistors and other components in an optimally aerodynamic manner. As a result, this measure alone reduces train resistance by 5 to 8%, depending on the required scope of roof-mounted equipment. In this context, special attention was given to optimizing the design with regard to the requirements relating to side winds and to minimizing the sonic boom when entering tunnels *(Fig. 8)*.

In addition to this noticeable measure, other aspects were implemented. By using a face-to-face arrangement, two pantographs can now be integrated into one roof zone to save space *(Fig. 9)*. Apart from the aerodynamic benefits, such as reducing the number of six roof zones to four in four-system trainsets, there are also positive effects in the interior space, since the areas with lowered ceilings can be considerably reduced, and there is also less noise entering the vehicle. Maintenance is also simplified by concentrating the locations for the installation of equipment.

Compared to earlier Velaro trainsets, the bogie areas are now noticeably smaller and the design of the underfloor area has again been optimized. This included redesigning the exhaust openings of the coolers in the traction system, improving the transition zones to and from the bogie, and the bogie skirts themselves.

The redesign of the front section (see above) also involved large amounts of detailed work on aerodynamic optimization, for instance on the spoiler elements. Overall, it can be said that the entire revision of the aerodynamic concept has led to a reduction of the equivalent air resistance surface by approx. 20%,

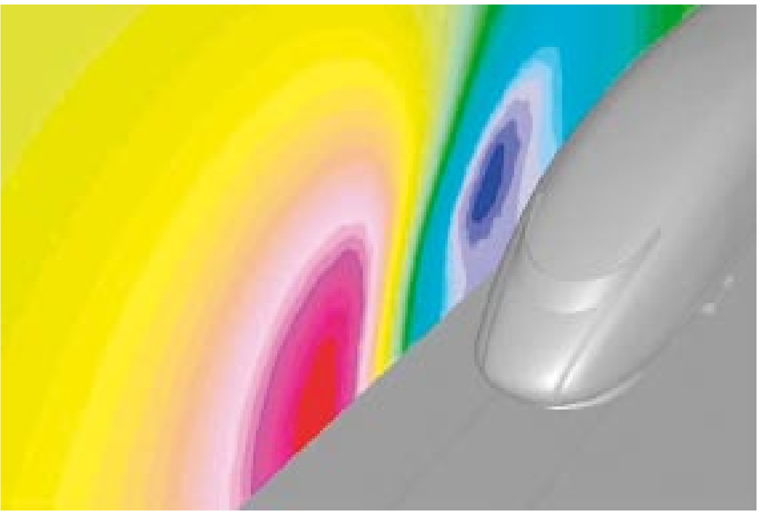

Fig. 8: Flow simulation of the end car

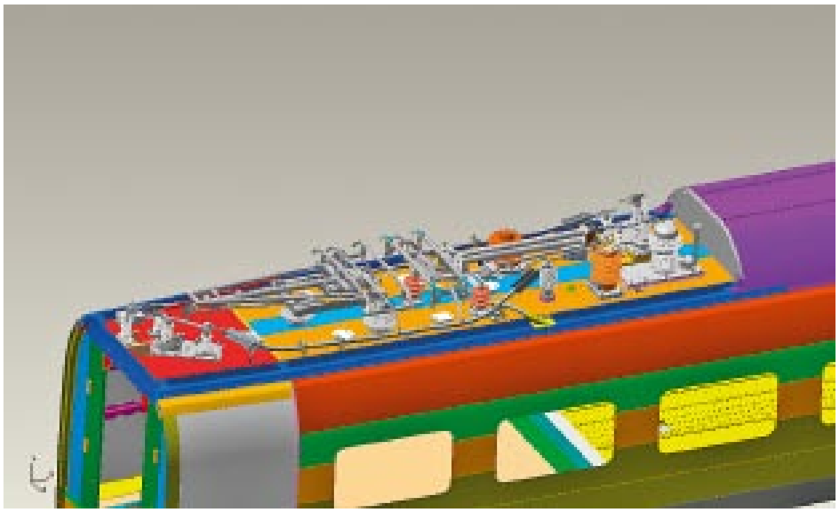

Fig. 9: Arrangement of two pantographs in the elevated roof zone

which means that the Velaro trainsets of the most recent generation will save considerably more energy.

## 3.4 Further developments of the bogies

The design of the SF500 bogie, well-known from the ICE 3 and meanwhile also service-proven in Europe and Asia, already underwent further optimization and improvement in the predecessor projects for Velaro China and Velaro Russia. In addition to changes which serve for better production of the bogie frame, such as new attachment of the axle guide to the bogie frame, many details have been changed. In the newest generation of the Velaro, the SF500 is equipped with a central cable transfer interface. This design was chosen in order to route the numerous transmitter and sensor lines from the axle boxes between the longitudinal members of the bogie frame and from there to the car body in a protected manner. This further reduces the susceptibility of the sensor systems and their wiring from kicked up ice and stones. In this area, sensor bearings will also be used in the future. These are journal bearings that can handle all required monitoring tasks together with a directly attached sensor head, which can be equipped as desired. The benefit lies in a more compact form of construction which is easier to protect.

Among other things, the transition to integrated bearing sensor systems was also driven by the introduction of Siemens' own vehicle monitoring and diagnosis system. In addition to the functions for monitoring journal bearing temperature, redundant detection on non-rotating axles and running stability, depending on the version, this system offers status monitoring for the entire bogie and its component groups such as wheelsets, journal bearings, dampers, etc. *(Fig. 10)*.

After many years of development and continuous successful testing in the locomotive field, the decision was made to at least provide this system in future Velaro trainsets as a preliminary setup. The significant objectives, which are targeted in the integration of bogie diagnostics, are the improved ability to detect impending damage and, as a result, the transition from costly preventive maintenance with a rigid adherence to mileage limits toward cost-optimized maintenance shortly before component failure. The result is better utilization of component service life while simultaneously increasing vehicle availability.

Another step in reducing maintenance costs will involve the introduction of a larger journal bearing. This will increase the service life of the wheelset and result in further maintenance benefits by offering the option of re-greasing.

## 3.5 Traction equipment and onboard power system

The Velaro China and Velaro Russia projects benefited from the introduction of high-voltage IGBT technology for traction purposes in the high-speed trains of Siemens AG. Since the 2008 Summer Olympics in Beijing, the CRH 3 trainsets in China have been in robust continuous operation *(Fig. 11)*. The distances traveled per year and per train are considerably above 550,000 km. The attained reliability of all systems is very satisfying, particularly that of the traction system. Due to the solid preparation, testing and maturity of the IGBT technology in the area of traction equipment for locomotives and regional trains, the breakdown in reliability commonly associated with the introduction of a new technology was successfully avoided.

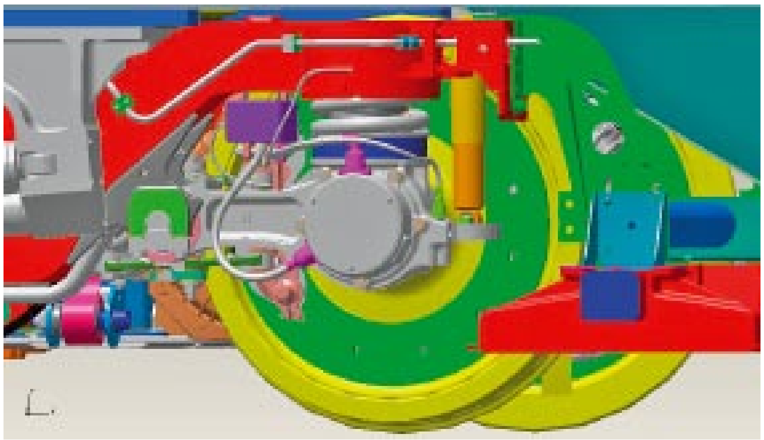

Fig. 10: Integrated sensors on the axle box

**Fig. 11: Velaro China: CRH 3**

The next developmental stage has been tested in the Velaro Russia since the beginning of the year. Here, the DC link circuit of the converter is operating in the high performance range directly on the 3 kV DC overhead contact line through a line filter. The test results are very pleasing. This is also due to the preceding development and optimization in a regional train project.

Consequently, a mature and proven IGBT technology in the 25 kV 50 Hz and 3 kV DC applications is already available for the new Velaro generation. It is currently being complemented with the 15 kV 16.7 Hz and 1.5 kV DC applications. However, neither of the two traction power supplies places higher demands on the technology nor requires fundamental further developments – a positive circumstance for the Velaro family in terms of the reliability. The transition from the group drive with four motors (1C4M) to a group drive with two motors (1C2M) *(see Table 1)* marks an additional step in improving the drive technology. It simplifies maintenance: in the future, it will only be necessary to maintain the same diameter on two wheelsets of the same bogie, instead of on four wheelsets of two different bogies.

The onboard power system for feeding HVAC systems, pumps, fans and compressors has also been continuously developed and made more reliable in recent years. The most recent step is the concept adopted from the Velaro China: namely, connecting four power packs directly to the input end of the DC link circuit *(Fig. 12)*. An IGBT converter connected to a transformer for subsequent galvanic separation of the voltage levels for the traction equipment and the onboard power system provides a common supply to a 3x 440 /60 Hz onboard power system busbar with self-synchronizing outputs. The quality of the onboard power system is very good due to sinus and EMC filtering.

This concept is particularly characterized by its high reliability and availability. Failure of a power pack does not cause any restrictions in vehicle operation. Even if there is a direct short-circuit of the AC busbar, a disconnector can be used to keep at least half of the trainset operational.

In the course of the work on the Velaro platform, a power pack variant was designed which implements galvanic separation between the traction equipment and the onboard power system by means of a medium-frequency transformer. The advantage of this medium-frequency electrical separation lies in the very compact and lightweight design, which is several sizes smaller than the previous ver-

**Table 1: Development of the Siemens traction technology**

| Vehicle | Technology | Configuration | Output / Speed* |
|---|---|---|---|
| ICE 3 | GTO 1-/4-system | 1C4M | 8.0 MW / 367 km/h |
| Velaro E | GTO 1-system | 1C4M | 8.8 MW / 403.7 km/h |
| Velaro CN | IGBT 1-system | 1C4M | 8.8 MW / 394.3 km/h |
| Velaro RUS | IGBT 2-system | 1C4M | 8.0 MW / 281 km/h |
| Velaro D | IGBT 4-system | 1C2M | 8.0 MW / – |

* maximum speed reached thus far without modifications to the hardware and infrastructure

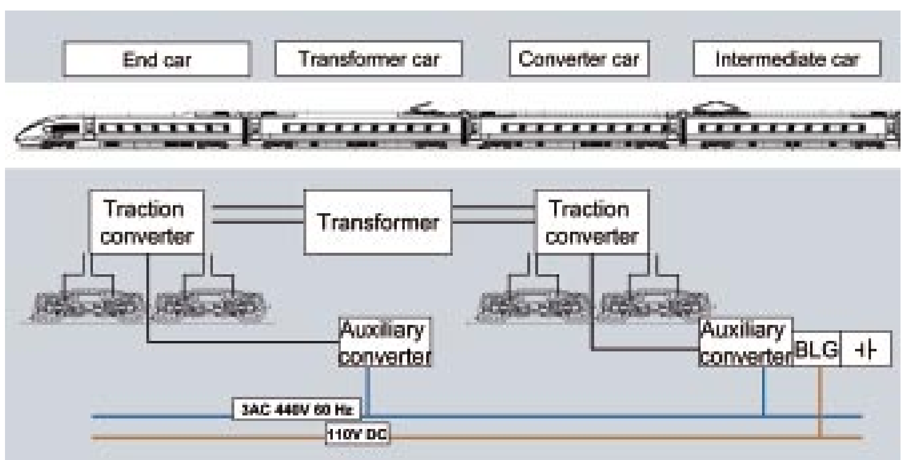


**Fig. 12: Layout of traction equipment and onboard power system for the Velaro**

sion. Another benefit lies in the fact that the system is largely insensitive to different input voltages, which inevitably occur in multi-system applications. This medium-frequency electrical separation is known, among other things, from the power packs used in passenger coaches and in the VT 605 series of multiple-unit trains.

### 3.6 Maintenance

The target matrix in 2.1 *(Fig. 3)* illustrates the strong focus on the subject of maintenance for the Velaro trainsets. The following text describes the maintenance procedure in a few sectors.

An important plus point for the Velaro trainsets is the fact that the fourth generation of these trains is meanwhile in development and a lot of knowledge acquired from several hundred million kilometers of operation by the previous generations is constantly flowing into further development. This is being boosted all the more by the fact that Siemens is carrying out the maintenance on the Spanish Velaro fleet together with RENFE in a joint venture named NERTUS and therefore has the direct opportunity to collect operating data for the purpose of optimizing maintenance – as well as the vehicle itself – with its own improvement programs.

Of course, this is also done in close cooperation with existing customers. For instance, adaptations to the train braking management system can reduce brake pad wear. This was implemented in cooperation with Deutsche Bahn AG on the ICE 3 fleet.

Starting at the end of 2009, this area of activity will be further reinforced when the Velaro RUS trainsets start operating between Moscow and St. Petersburg. Siemens is fully responsible for vehicle maintenance there as well.

Apart from the positive influences which result from the feedback received from the maintenance shops, the link between maintenance and vehicle design has been getting much closer in early concept phases over the past several years. The same also applies to the inclusion of the experts from the field of reliability. In joint design reviews, the concept of every system is examined in terms of maintainability, maintenance costs as well as reliability and availability. Since the entire design of the trainsets has taken place three-dimensionally since the Velaro China project, this also results in some benefits that can be used in maintenance. For instance, 3D designs are spatially projected in a Virtual Reality Laboratory *(Fig. 13)* on a regular basis and discussed by the responsible persons from the design, production and maintenance departments.

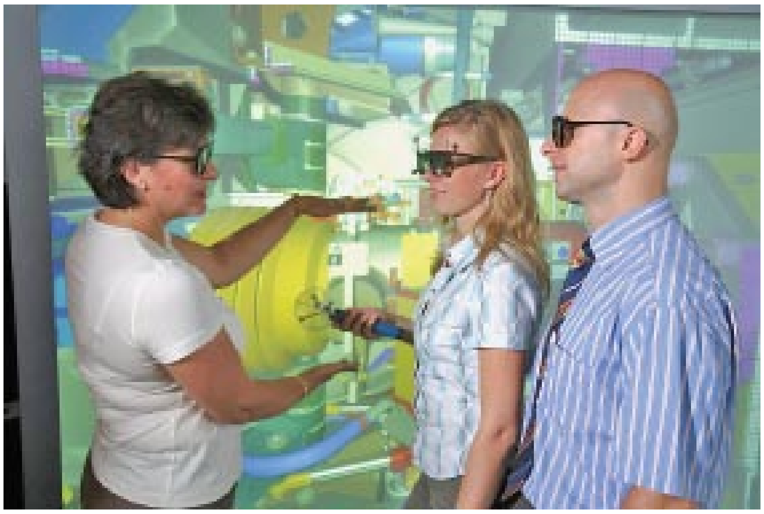

**Fig. 13: Virtual Reality Laboratory**

Three-dimensional depiction makes it easier to deal various topics, such as:
- examining the contacts between components and cable routes that are already detected at early stages,
- investigating options for installation and removal to ensure optimum maintainability of the vehicles at an early stage,
- determining an optimum sequence for assembly of the vehicles, and
- carrying out design reviews with customers and their own maintenance departments in order to take their wishes regarding their maintenance infrastructure into account. This is currently being implemented within the Velaro D project with the Deutsche Bahn AG.

This fundamentally different manner of proceeding in the development of the Velaro trainsets is paralleled by other constantly ongoing programs for lowering maintenance costs. The focus is not only on cost drivers such as the bogie (see 3.4) and the brake system, which, for instance, has been equipped with an oil-free compressor since Velaro Russia, but also on optimization of the maintenance processes and lengthening of the maintenance intervals are also advanced in detailed work *(Fig. 14)*.

### 3.7 Flexibility in the interior

The service life of a high-speed trainset is set at 30 years. While the major components such as bodyshell, bogies, traction equipment and brakes can remain in use for this period, there is a need to rework the interiors with their furnishings for passengers at a much earlier time. Seat covers, carpets, floor coverings and areas subject to high wear are worn out after only a few years of use and need to be replaced. And, of course, tastes also change over time and with them our sense of what is beautiful or attractive. This is shown, for instance, by the color design of the ICE 1 as compared to the ICE 3, which became operational approximately

Fig. 14: Maintenance of the Velaro E at Nertus in Spain

ten years later. During its refurbishment, the look and feel of the ICE 1 was adapted to the "corporate design" of the Deutsche Bahn AG preferred today.

In vehicle design it is necessary to consider that a general overhaul of the passenger areas will take place approximately twice in the life of a trainset, but changes due to altered uses of trains or additional functions will also take place from time to time.

This results in demands on the Velaro family that are summarized under the term "flexibility in the interior". It includes easy adaptability of seat spacing, flexibility in the integration of interior modules, such as glass partitions with interior doors, and the maximization of areas for interior design purposes.

In concrete terms, this includes a revision of the systems for fastening elements in the latest generation of the Velaro trainsets. In this case, the seats are connected to the floor by means of a rail, which makes it possible to shift seats freely in order to change seat spacing *(Fig. 15)*. Likewise, all other fastening points such as for tables are placed in such a manner that the large side areas of the interior remain untouched. In the event that interior furnishings have to be rearranged, this will avoid unsightly hole plugs and lower assembly costs since costly drilling in the floor will no longer be necessary.

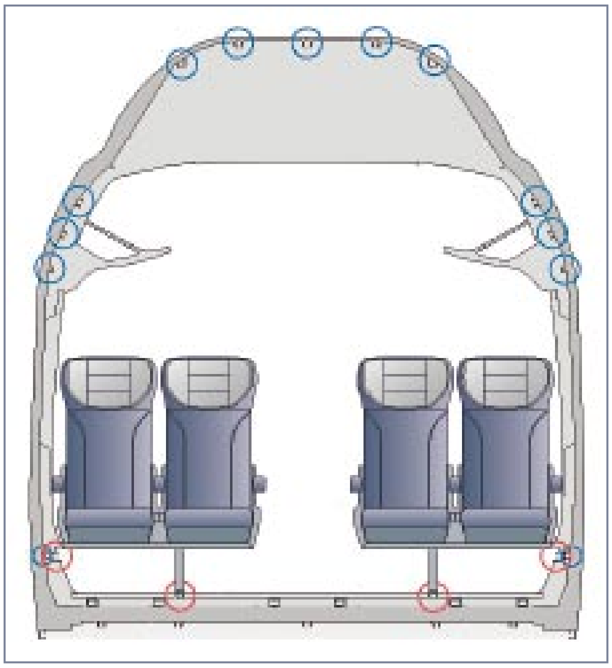

Fig. 15: Flexible interior design using continuous fastening rails

At the same time, modules are being developed which can be flexibly integrated into the interior areas and mounted solely on the fastening rails provided for seats and luggage racks. Rest areas, for example, can be set up by installing glass partitions. There is a special focus on being able to provide the operator with a service and catering concept, which is tailored to his requirements. This also includes the development of flexible trolley standing areas and modular galley concepts.

In the course of reorganizing the interiors, all functional spaces for the installation of, say, switchboards, operator panels, waste bins, etc. were concentrated in favor of maximizing the usable floor space for passengers and arranged at the end of the car next to entrances. Together with the washrooms, this results in an optimized functional area which, in the case of a Velaro intermediate car, results in an empty tube 18 meters long that can be used for passenger seating *(Fig. 16)*. With the Velaro concept, the limit of 500 seats in a 200-meter-long train is therefore easily exceeded (with classic 1 + 2 seating in 1st class).

Since the capacity of the Velaro has not yet been exhausted with 100 % occupation of all seats, the operator also has the option to carry standing passengers during peak traffic periods and therefore to improve the profitability of the system.

For the sake of completeness, it should be mentioned that the Velaro concept takes the needs of passengers with reduced mobility (PRM) fully into account. The corresponding TSI PRM is fully implemented and partially exceeded in the Velaro. Wheelchair users can safely reach their location via wide entries and aisles and easily find their way in the oversized universal rest rooms. And the way in the adjacent car to the dining car is also open thanks to the use of wide gangways between cars.

### 3.8 Reliability

As already explained, the reliability and availability of trainsets are highly signif-

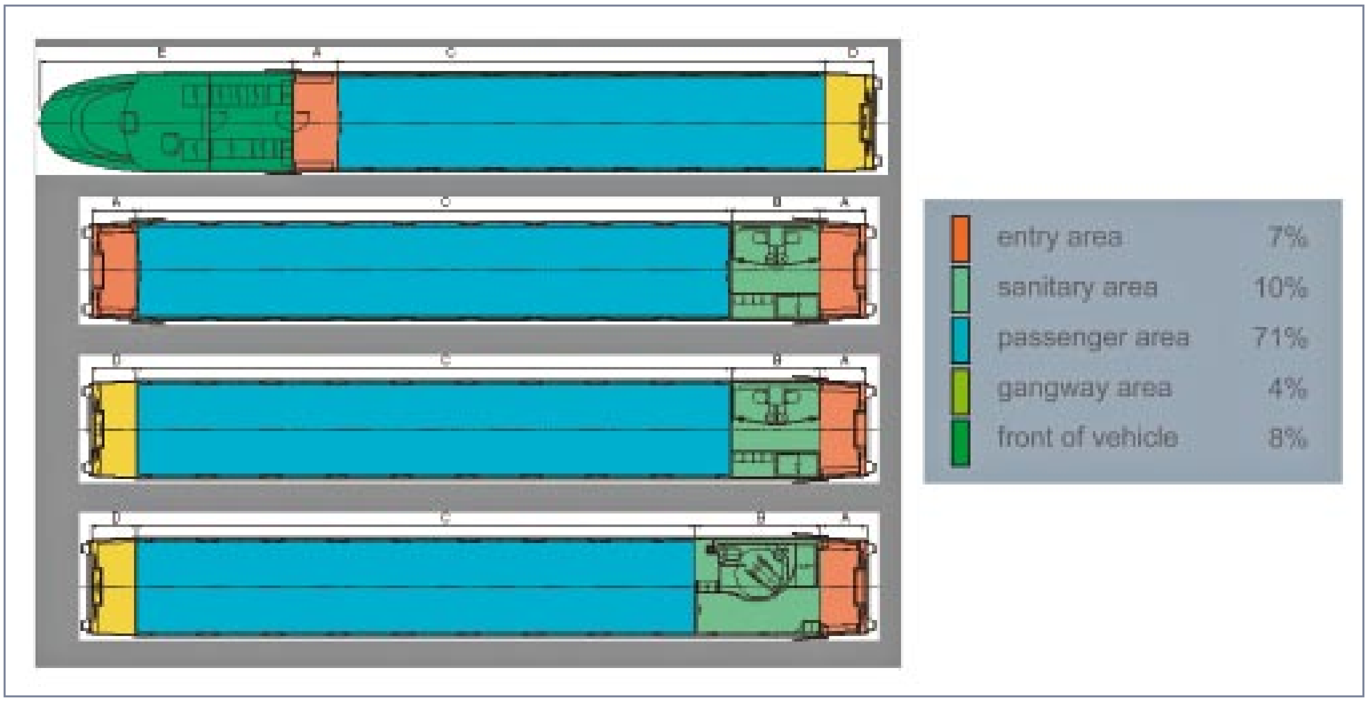


**Fig. 16: "Empty tube" principle for the largest possible usable floor area**

icant for ensuring economic operation. When it first entered operation, the ICE 3 had to battle a greater range of problems due to the revolutionary development step from the ICE 2. The German operator DB AG and the manufacturing consortium AGRE ICE were able to cooperate in order to tackle these issues quickly, resulting in noticeable improvements even within the first months of operation. The problems ultimately resulted from the fact that the proportion of new concept and design was very high in this vehicle. It was later possible to handle the systems better and improve reliability. The successor model, the Velaro E for Spain, was already able to provide much better reliability levels right from the beginning. This trend is currently continuing in China with the Velaro.

This observation allows various conclusions to be drawn:

- High proportions of new design and concept are associated with a risk of diminished reliability levels in operation, and
- Staying with proven designs and carefully improving them makes it possible to achieve better overall performance.

In the course of further developments, experts from the RAMS department – together with the designers and sub-contractors – are busy working on making not only the train systems but the train as an entire system more reliable. This is done by using the various insights gained from the Velaro projects that are in operation – whether it is in maintenance or directly from the operators. Regardless of the theoretical approach, the systems are examined using an error tree analysis, and the knowledge is brought back into changes in the system design.

The objective for further Velaro development is:
For every 1,000,000 kilometers traveled:

- no train should be out of operation for vehicle-related reasons, and
- only a maximum of four to five technical problems that cause delays of more than five minutes are allowed to occur.

In the twenty systems of the Velaro that have the greatest influence on reliability, target specifications were first developed and then the concept and design were discussed in joint workshops with the manufacturers. Many manufacturers were not immediately able to carry out substantial work on the subject. In retrospect, however, this method, which has been used for approximately two years, should increase reliability of the Velaro. Based on the fact that the Velaro is now in its fourth generation and currently does not require any revolutionary development steps, customers can assume that they will receive a mature and stable technology that is being developed further with great care.

## 4 Velaro D – the European

### 4.1 Invitation to tender for high speed trainsets of Deutsche Bahn AG

Shortly before Christmas 2007, Deutsche Bahn AG issued an invitation to tender for multi-system trains capable of operating throughout Europe. Bidders were required to submit their offers by the beginning of March 2008. The invitation to tender had been prepared by DB AG in a very professional manner. Apart from the hardcopy form, all specifications were also provided as importable files for a DP-based requirements engineering tool. Thanks to expe-

Fig. 17: Exterior design of the Velaro D – future Class 407 of DB AG

rience at Siemens, the bidding team was ready to work within a very short time and was able to comment on the more than 6,000 individual requirements in the tool and also send them back to DB AG for bid submission. This simplified the very structured bidder meetings, in which every bidder has to present his offer.

The comparison of the DB AG specifications and the specifications upon which the Velaro platform development had been based showed a high degree of overlap – a confirmation of the solid groundwork that was laid back in 2006. Ultimately, only the ongoing and far advanced platform work made it possible for a serious offer for such a sophisticated vehicle to be submitted within such a short time.

The invitation to tender was for a four-system trainset built for a speed of 320 km/h for operation in Germany, France, Belgium and optionally Switzerland and the Netherlands. It had to provide seating for at least 420 passengers and demonstrate that could carry a loading of 150 %.

After intensive negotiations, Deutsche Bahn AG made its decision to choose the offered Velaro D. Almost one year after the start of the invitation to tender, the contract was signed by the CEOs of DB AG and Siemens AG in Berlin. Including the large dining area, lounge space for train personnel and train manager compartment, the Velaro D will have a total of 460 seats – approximately 30 seats more than today's Class 406 and a significant result of target-oriented vehicle development.

It is now proving to be a major advantage that the basic concept of the Velaro was implemented as a four-system train. The subsequent integration of heavy 15 kV 16.7 Hz traction equipment, for instance, would pose significant problems to any manufacturer. In the case of the Velaro D, the layout of the previously fictive "maximum train" could be directly taken over. The fact that major further developments, such as the new bodyshell for the front section, had already been under construction in the company since the end of 2007 will also make it possible to meet the very demanding deadlines of the Velaro D project. Production of the first bodyshell components has been in progress since April. Assembly will start in October 2009. The first complete Velaro D trainset will enter the commissioning phase in August 2010 and be certified in Germany, Belgium and France starting in January 2011 *(Fig. 17)*. This would mean a period of two years from conclusion of the contract to fully operating train – also one of the goals which the platform development had set for itself.

It should be noted that when seen against the described roots of the Velaro family, which originated from the ICE 3, the fourth generation of the Velaro will now be "coming home". The ongoing further developments and the work performed in advance, the constant feedback of knowledge from operations and maintenance, and the mature technology are responsible for this.

– A 156 –

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*(Picture credits: All pictures – Siemens AG)*

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