9. DH Build

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9.1. Introduction

After ULSAB Phase 1 was successfully completed, the ULSAB Consortium decided to proceed with the ULSAB program into Phase 2. This involved proceeding from a conceptual study to the real world hardware, whereby the predicted mass savings and improved performance could be proven by actual product.

Due to the experience in laser welding, Porsche's R & D Center in Weissach, Germany was chosen for the execution of the 13 DH builds.

Figure 9.1-1 Prototype Shop

9.2. Joining Technologies

9.2.1. Laser Welding

For more than 10 years the laser has shown its production capability. The first auto body application was the blank welding of the floor panel for the Audi 100. Laser welding in the assembly process was first brought into a production plant by BMW for the roof welding of its former touring model 3 series and Volvo for the roof welding of the 850 model.

Since then, especially during the last three years, an increasing number of auto manufacturers have installed laser welding equipment within their production lines.

Today laser welding applications in production plants are utilized all over the auto body, such as the front end, under body, closure panels and roof panel.

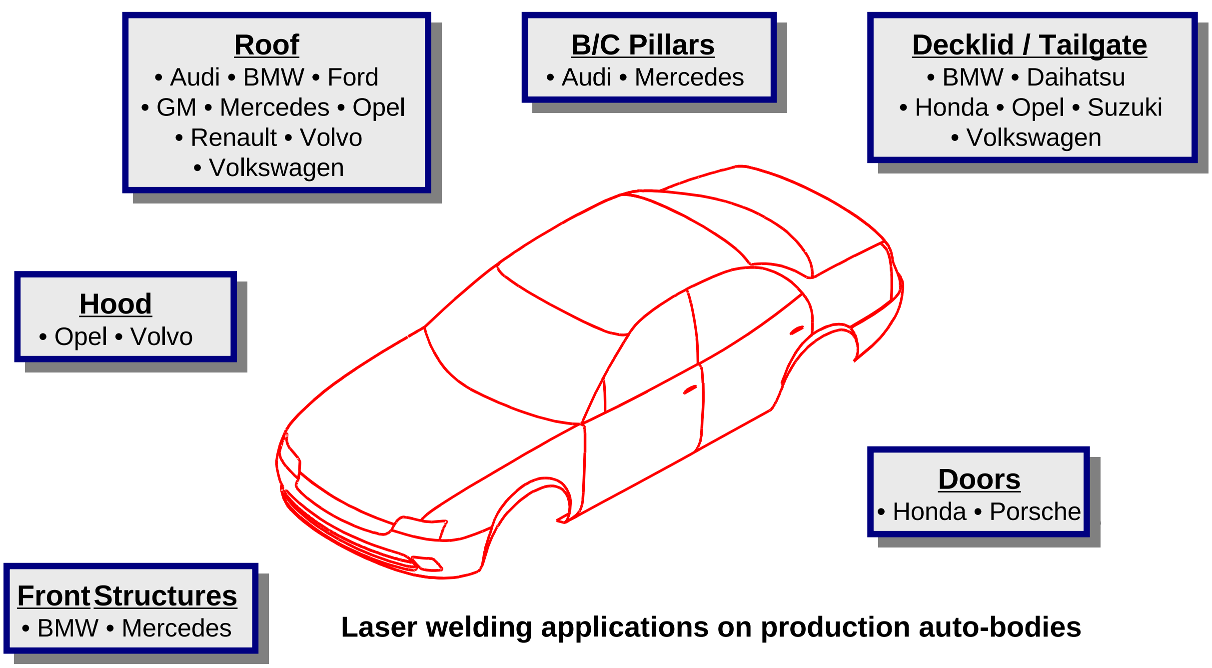
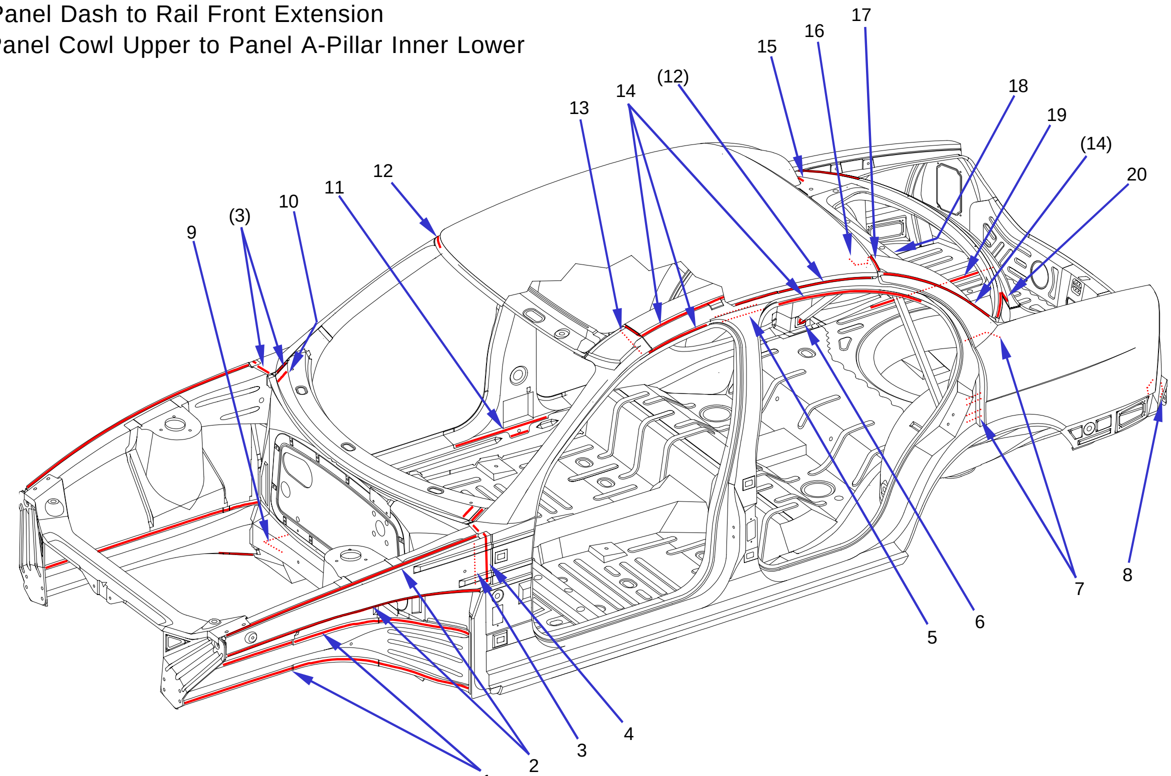


Fig. 9.2.1-1 Laser Welding in Assembly

The major reasons for using laser welding is the predominantly high static and dynamic strength of the joints, one side weld access for the welding equipment, small thermic impact zone and good aesthetic look at the joint area. The total length of the laser welding seams for the assembly on the demonstration hardware is 18.28 meters.

1. Rail Front Outer to Rail Front Inner
2. Rail Fender Support Inner to Rail Fender Support Outer
3. Panel Body Side Outer to Panel A-Pillar Inner Lower
4. Rail Fender Support Outer to Panel Body Side Outer
5. Panel B-Pillar Inner to Rail Side Roof
6. Bracket Member Pass Through Lower to Member Pass Through
7. Panel Wheelhouse Inner to Rail Side Roof
8. Panel Back to Rail Rear Inner and Rail Rear Outer
9. Panel Dash to Rail Front Extension
10. Panel Cowl Upper to Panel A-Pillar Inner Lower



11. Panel B-Pillar Inner to Panel Rocker Inner
12. Panel Roof to Panel Body Side Outer
13. Rail Side Roof to Panel A-Pillar Inner Upper
14. Panel Body Side Outer to Rail Side Roof
15. Panel Package Tray Upper to Support Package Tray
16. Support Panel Rear Header to Rail Side Roof
17. Panel Roof to Rail Side Roof
18. Member Pass Through to Brkt Member Pass Through Upr Frt & Rear
19. Rail Rear Outer to Rail Rear Inner
20. Panel Package Tray Upper to Panel Gutter Decklid

Figure 9.2.1-2 Laser Welding on ULSAB Demonstration Hardware

9.2.2. Spot Welding

Spot welding is for all OEMs a well-experienced, reliable, affordable joining technique for steel auto bodies, even with zinc-coated steel materials. Porsche, for example, has been producing cars since 1977 with 100% zinc coated steel sheet metal and was the first company in the world practicing this. Now, more and more OEMs are switching to 100% zinc coated materials to improve corrosion protection and to give a long time anti-corrosion guarantee. Also for ULSAB, 100% of the material is double side zinc coated.

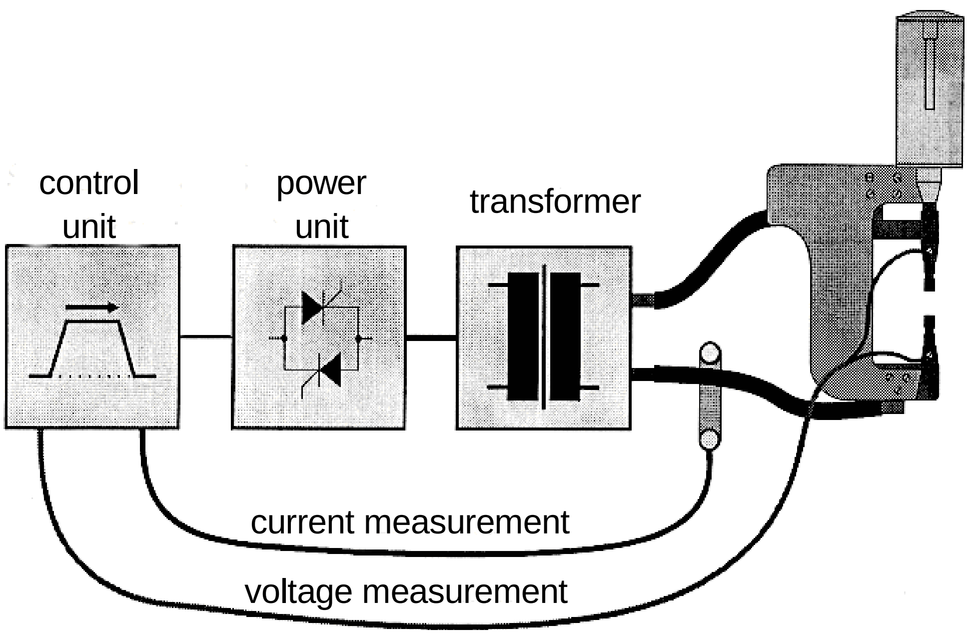
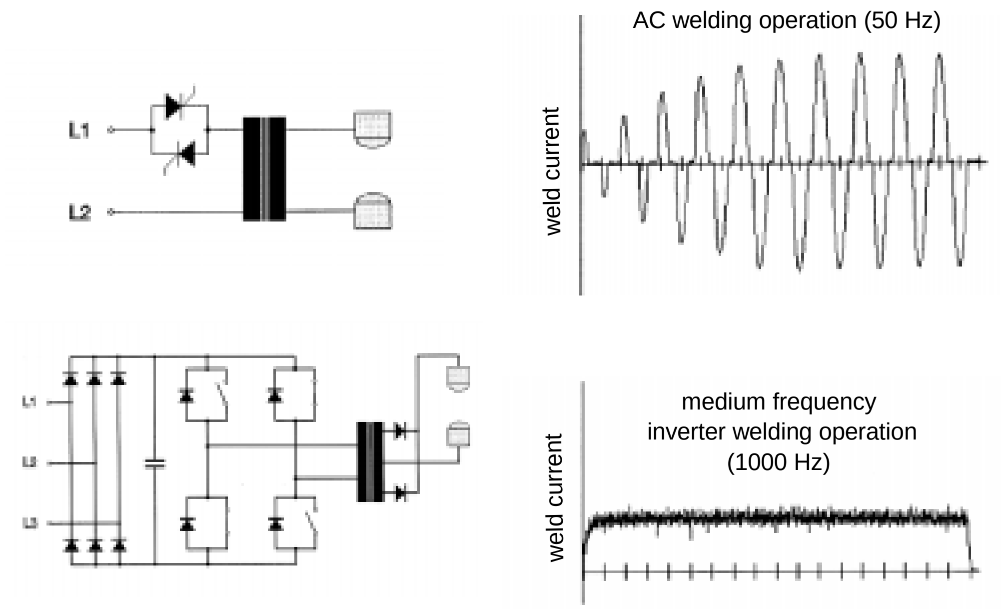


Figure 9.2.2-1 Configuration of a Welding System

Porsche's R & D Center Body Assembly Facility utilizes computer controlled medium frequency (1000 Hz) welding equipment. This system uses calibration to ensure that the welding current is maintained at a constant level. Thereby providing a good weld without disturbances and achieving optimum settings for welding time, welding current and electrode force. Having established the optimum setting, the data is stored in the computer enabling the use of the 'control mode' to ensure all subsequent welding operations achieve the same optimum integrity.

These control processes inevitably necessitate fast welding current sources. This requirement is fulfilled by medium frequency inverters with a response time of one millisecond at an inverter frequency of 1000 Hz and by the substantially faster transistor DC technology.



Comparison of the control response of thyristors and inverter controllers

Figure 9.2.2-2

The system is sensitive to:

- main voltage fluctuations
- shunts
- electrode wear (automatic stepper function)
- electrode force fluctuations
- small edge distances
- welding splashes
- changes from two sheet to multiple sheet welds

The control process compensates the various influencing factors by increasing or reducing the current strength and extending the welding time. Extension of the welding time can be limited.

Welding splashes are monitored via output of an error message, with optional shutdown of the welding current.

Optimum adaptation to each weld spot guarantees that the required strength for weld joints is maintained throughout broad ranges.

Figure 9.2.2-3 Medium Frequency Spot Welding Equipment

Spot welding is used on ULSAB in all areas with suitable weld access and normal structural loads.

The assembly of the demonstration hardware uses 2,126 spot welds.

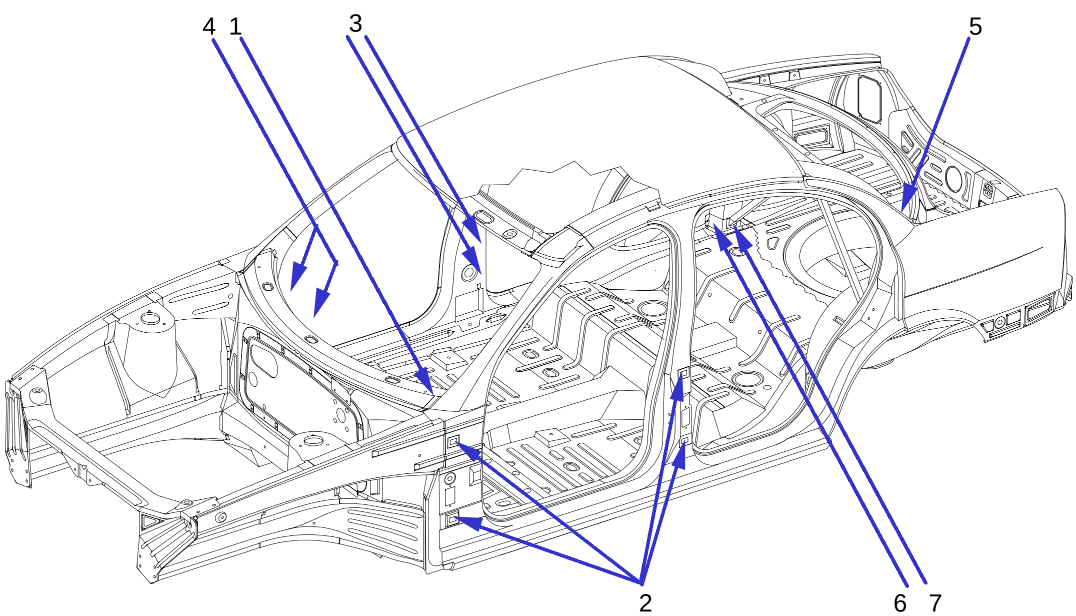
9.2.3. Active Gas Metal Arc Welding (MAG)

Active Gas Metal Arc Welding, or similar joining techniques, is used at all OEMs in locations with no weld access for spot welding or in areas with high stresses due to its strong structural behavior in comparison to spot welding.

The disadvantages of this process, like slow welding speed, big heat impact zone, and pollution by weld fumes, especially with zinc coated materials, forced many OEMs to reduce it to a minimal amount.

The targets for ULSAB were established to minimize the MAG welding seams. MAG welding is only used on the ULSAB body structure at locations without weld access for spot and laser welding.

In total, there are 1.5 meters of MAG welding on the DH structure.



1. Panel A-Piller Inner Lower to Panel Cowl Upper
2. Door Hinges to Panel Body Side Outer
3. Door Hinges to Panel B-Pillar Inner
4. Door Hinges to Panel A-Pillar Inner
5. Support Package Tray to Rail Side Roof
6. Bracket Roof Rail Mount to Rail Side Roof
7. Bracket Member Pass Through Lower to Rail Side Roof

Figure 9.2.3-1 MAG Welding on ULSAB Demonstration Hardware

9.2.4. Adhesive Bonding

The ULSAB steel sandwich material cannot resist the high temperatures during the painting process for body structures. Therefore this material is only suitable for parts which are assembled to the body after the painting procedure. Another factor is the non-weldability of the ULSAB sandwich material.

So for the two parts on ULSAB made of steel sandwich adhesive bonding is the chosen joining technology.

It has not only a structural function, it also provides sealing. The two panels made from steel sandwich material are the Panel Dash Insert (Part No. 022) and the Panel Spare Tire Tub (Part No. 050).

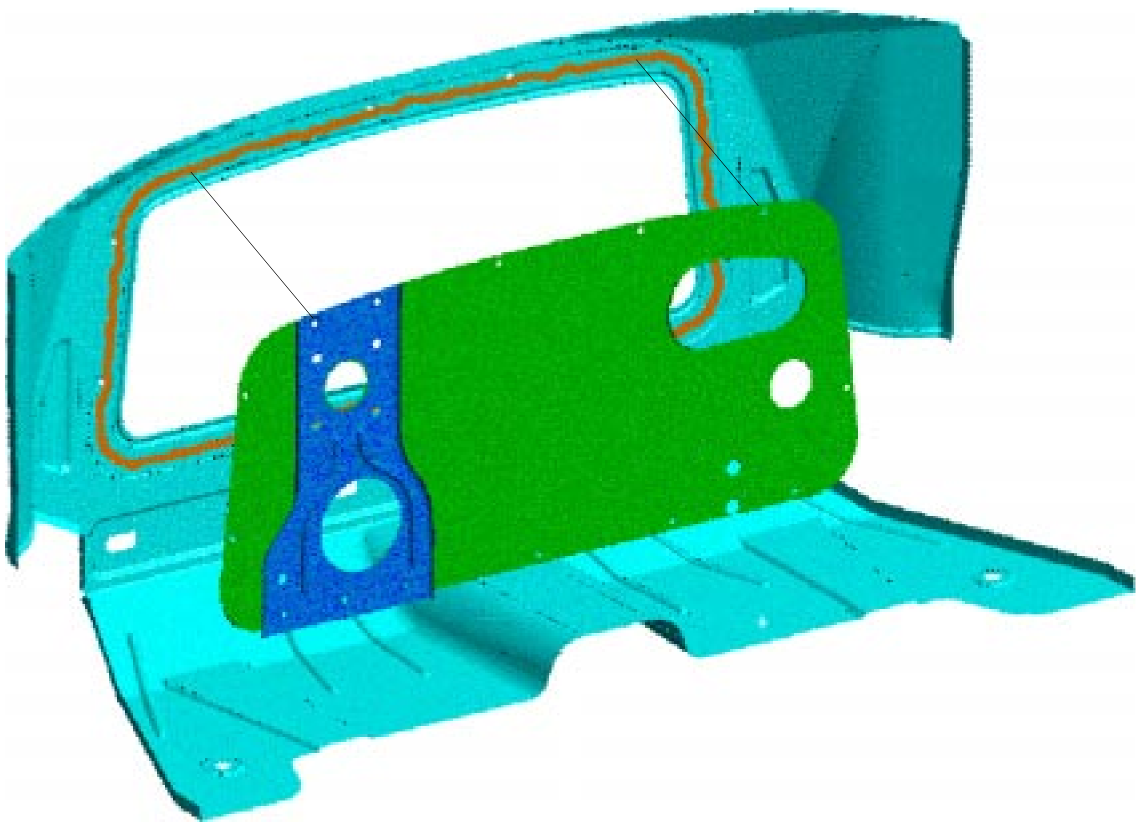


Figure 9.2.4-1 Bonding at Panel Dash Insert

In the production line, the panel dash insert will be assembled to the painted body structure as part of the instrument panel module. This includes the instrument panel, steering column, air conditioning system and pedal system. The panel dash insert is adhesive bonded and additionally bolted to dash panel. The bolting is necessary to keep the part in position until the bonding material is hardened.

The panel spare tire tub will be assembled to the painted body structure as a module including the spare tire and the repair tools. The module is bonded to the structure. The operation does not require additional fixturing.

The bonding material is a two component, non-conductive, high modulus, high viscous, chemically-curing polyurethane adhesive/sealant that cures almost independently of temperature and moisture. It is Betaseal X 2500 produced by Gurit Essex.

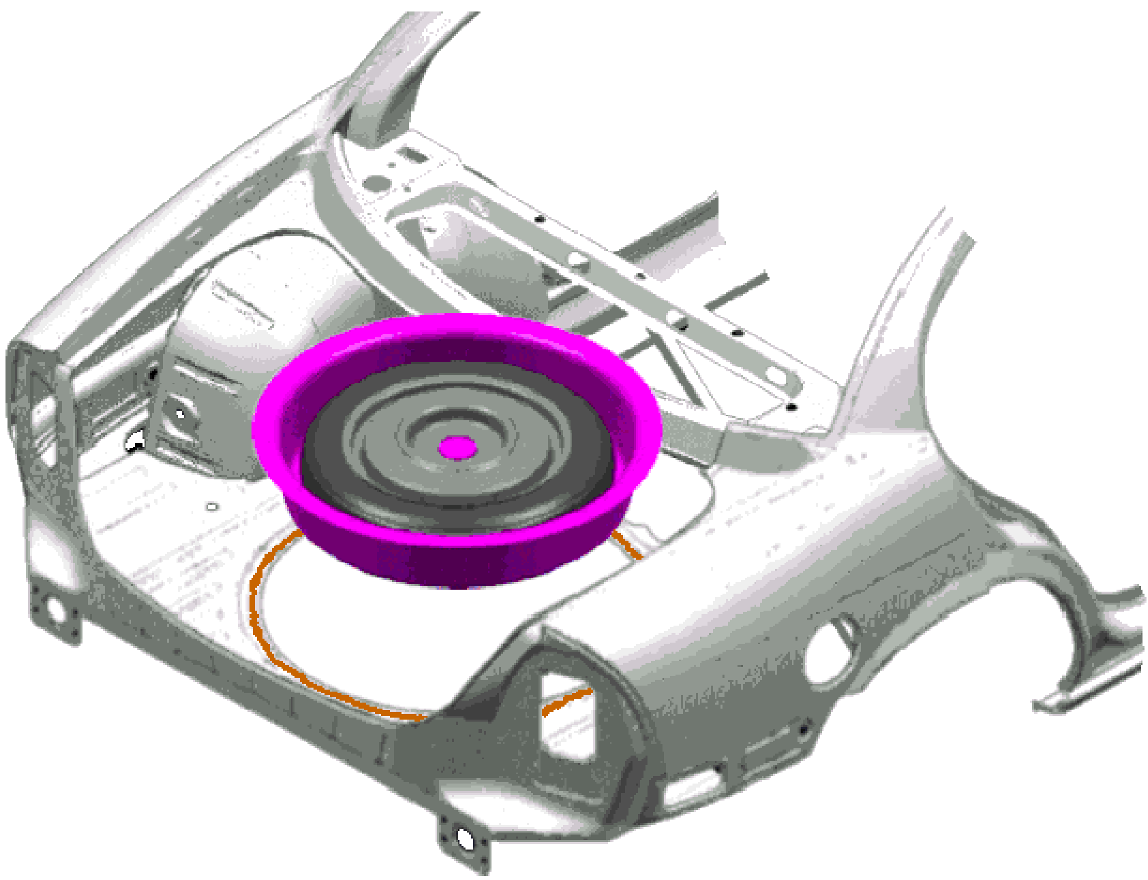


Figure 9.2.4-2 Bonding at Panel Spare Tire Tub

Technical Data	
Basis	Polyurethane prepolymer
Color	black
Solids content (GM 042.0)	>98%
Flash Point	>100° C
Processing temperature	ideal 10° C - 35° C
Working time (Processing time)	approx. 10 min. at 23° C/50% r.h.
Sagging behavior	good, non-sagging
Ultimate tensile strength (DIN 53 504)	> 5.5 MPa
Percentage elongation (DIN 53 504)	> 200%
Combined tension (GM 021) and shear resistance	> 4.5 MPa
G-Modulus	> 2.5 MPa
Specific electrical (volume resistivity)	> 10 Ω cm
Abrasion resistance	Extremely high
Recovery (DIN 52 458)	approx. 99%
Temperature stability	- 40° C at 100° C (for short periods up to 140° C)
Resistance to chemicals	Highly resistant to aqueous chemicals, petrol (in cured conditions) alcohol and oils. Conditionally resistant to esters, aromatics and and chlorinated hydrocarbons.
Preparation of bonding surface	All bonding surfaces must be free of dirt, dust, water, oil and grease. In general, surfaces should be primed.

9.3. Flexible Modular Assembly Fixture System

The body shop in Porsche's R & D Center used a highly flexible modular fixture system for the DH assembly. It is based on standardized units, which are adjustable in all directions.

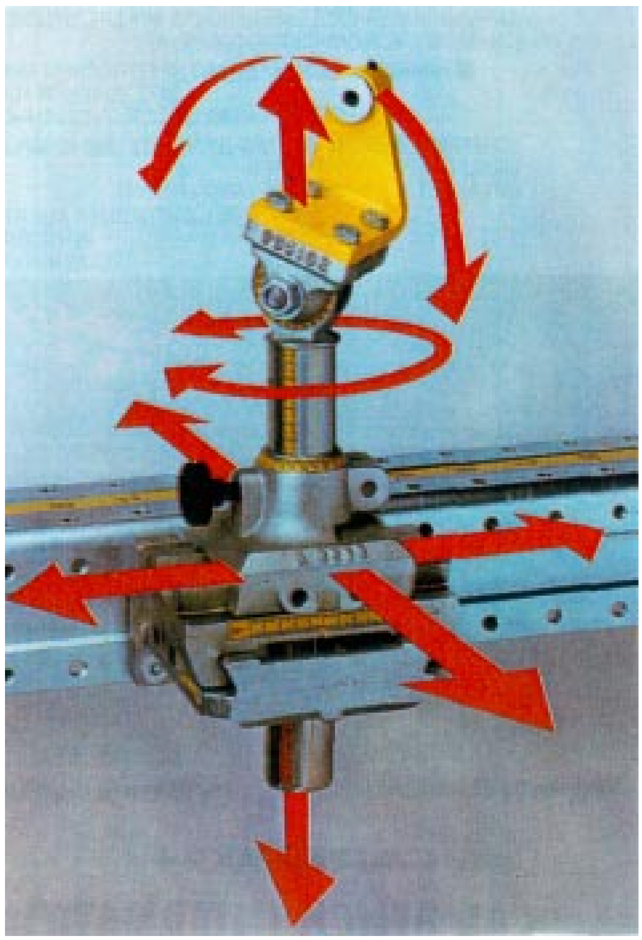


Figure 9.3-1 Assembly Fixture Module

There are many advantages of this fixture system. 95% of the elements in a fixture are from the standardized module system and can be used also for other car programs.

Figure 9.3-2a Assembly Fixture Module Detail

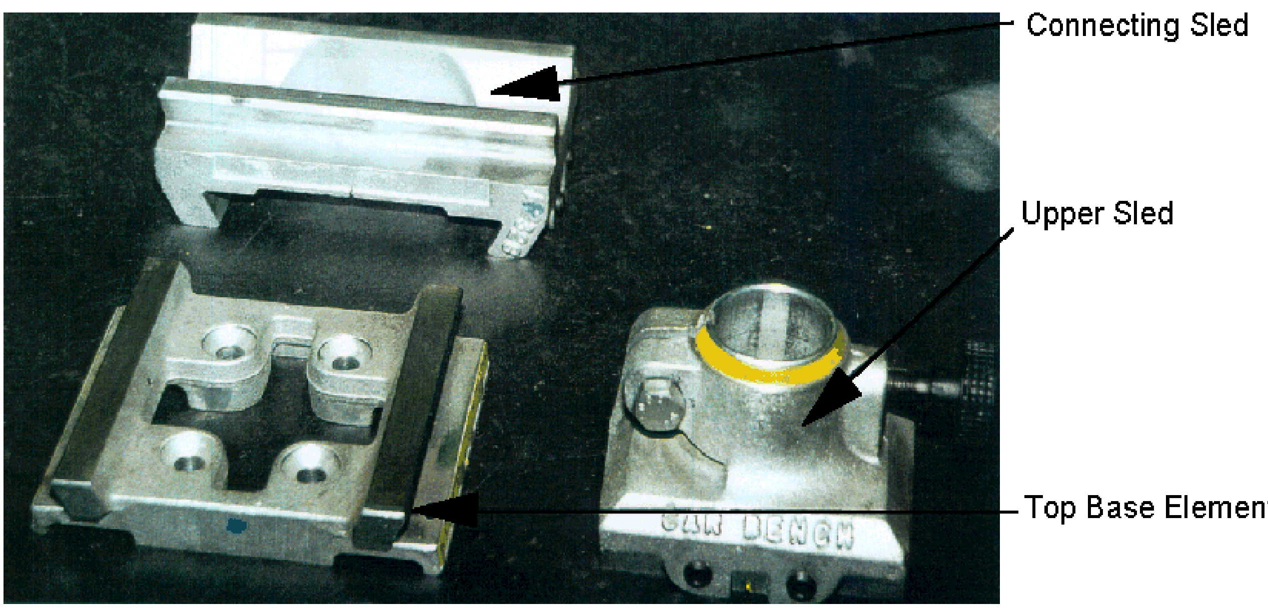


Figure 9.3-2b Assembly Fixture Module Detail

The fixture design performed in CATIA was very efficient, because all models were accessible from the CAD data bank. Therefore, the construction time for assembly fixtures was reduced and modifications or corrections of existing assembly fixtures could be implemented rapidly.

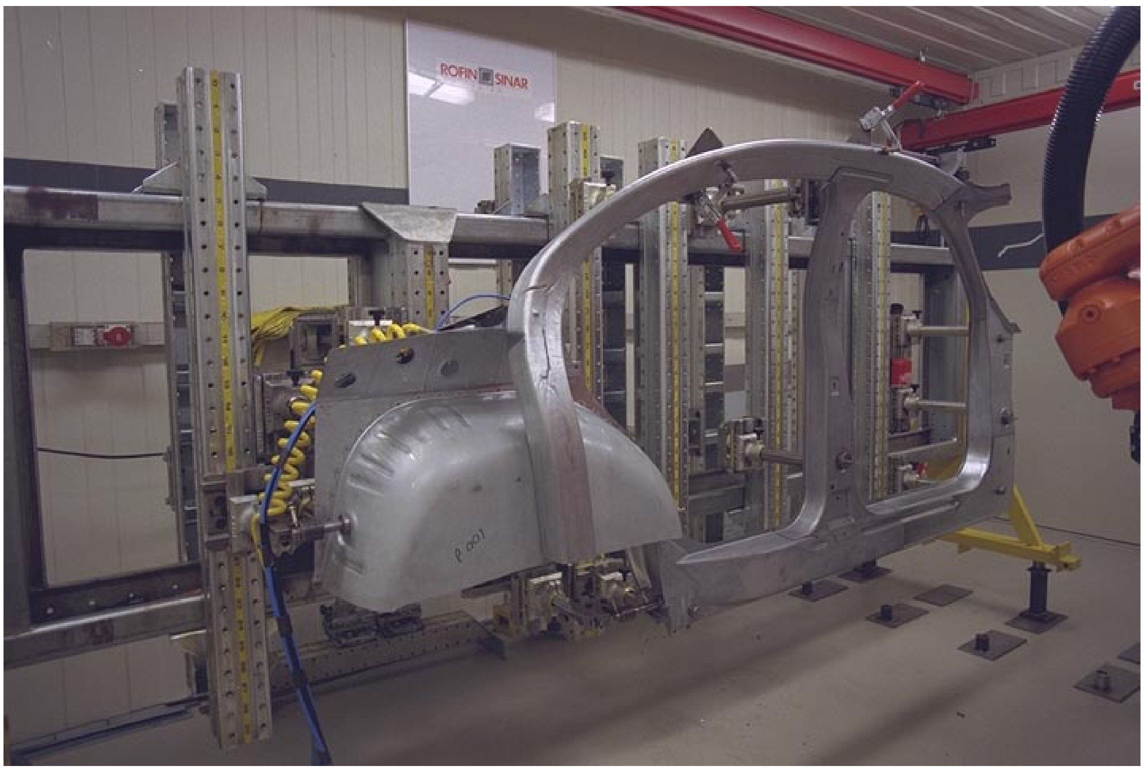


Figure 9.3-3 Assembly Fixture - Bodyside Inner Subassembly

Porsche is using the flexible modular system in two ways.

The first is the so-called shuttle system, which is related to the set-up pallets. The shuttles for different assemblies are stored in a shuttle magazine. During the assembly operation the shuttle is fixed on a set-up pallet. The changeover of various assembly shuttles on a set-up pallet is a very fast process. These assembly shuttles are mobile and can be used at different locations.

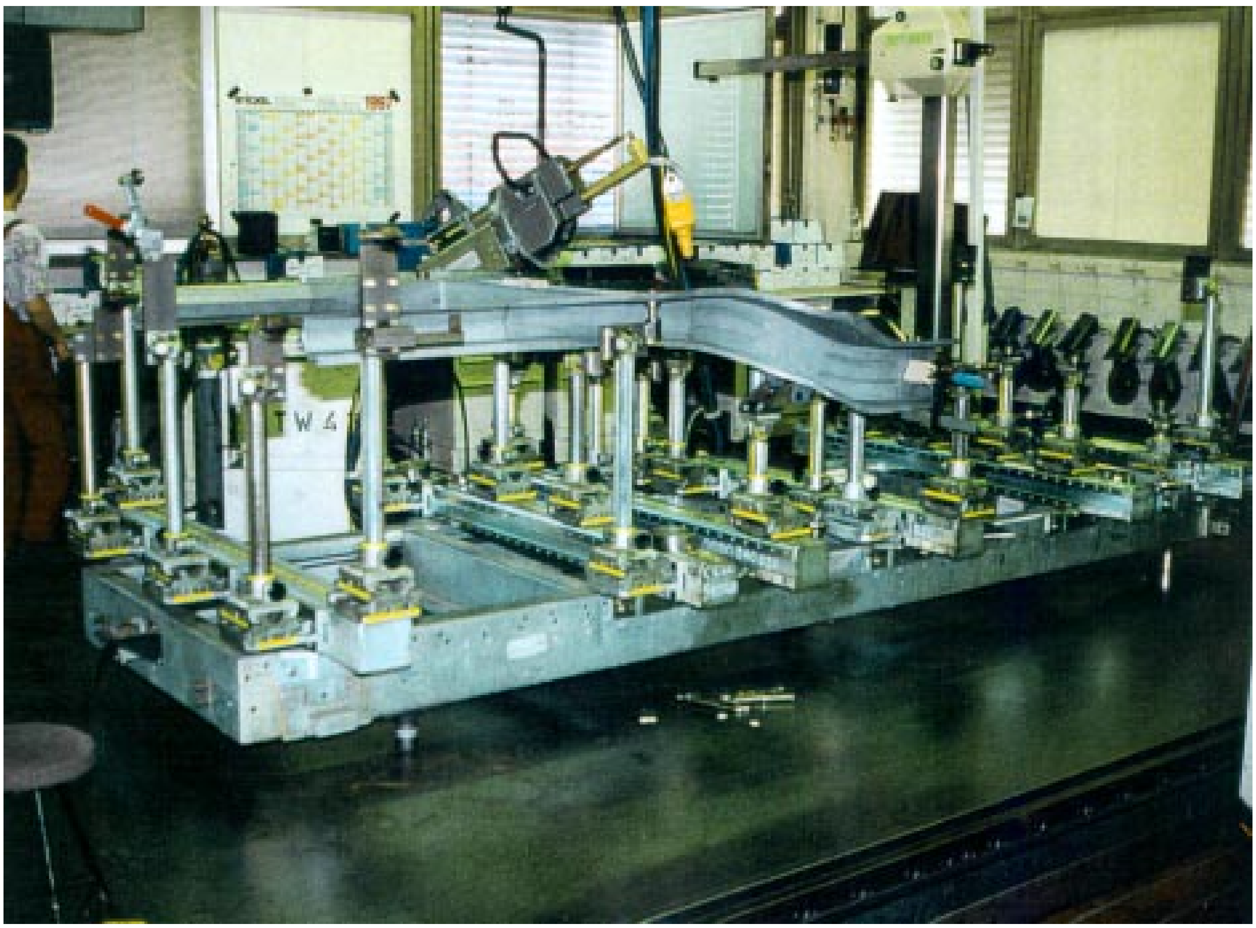


Figure 9.3-4 Assembly Fixture Shuttle on Setup Pallet

The second method is the utilization of a rolling device that supports the modular assembly fixtures independent from set-up pallets. These assembly fixtures work at any location.

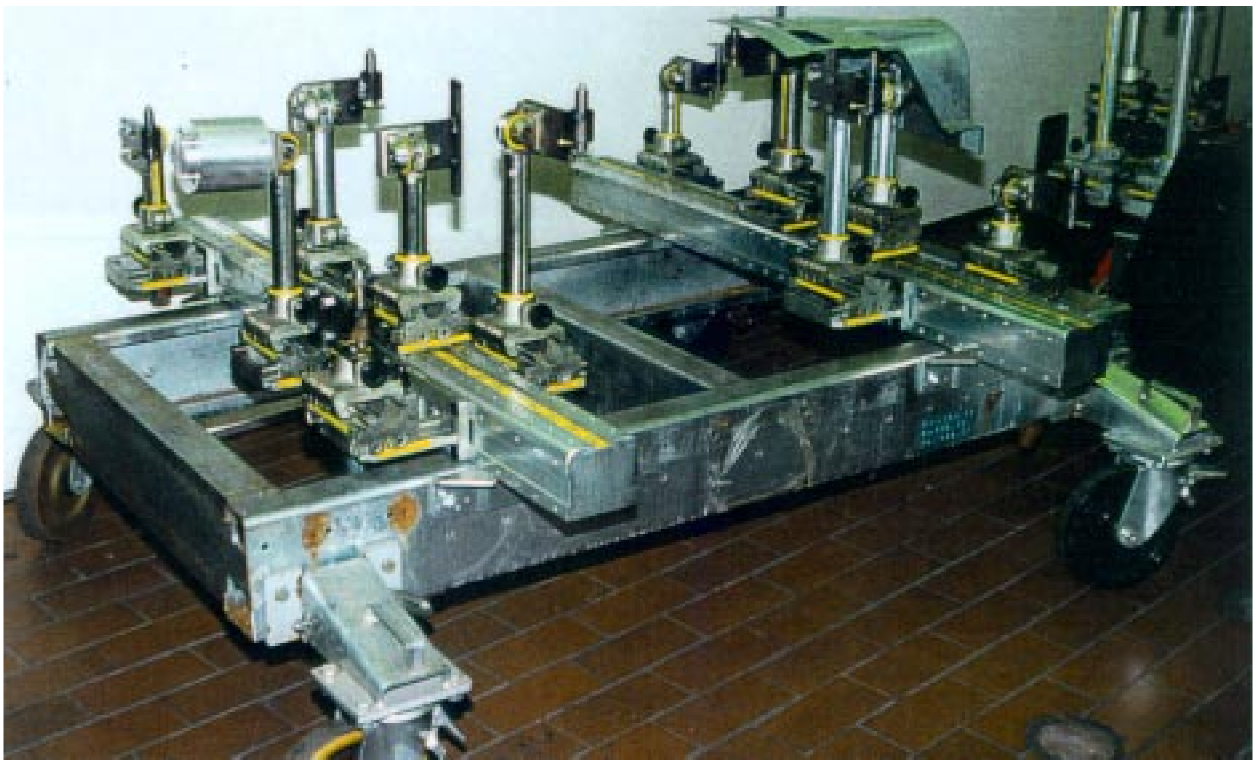


Figure 9.3-5 Mobile Assembly Fixture - Shock Tower Front SubAssembly RH/LH

9.4. Design of Assembly Fixtures

All fixtures are developed with a CAD system (CATIA) based on the existing design data. The CAD data models of the fixture system modules are available from a data bank.

Figure 9.4-1 Fixture Development on CAD System

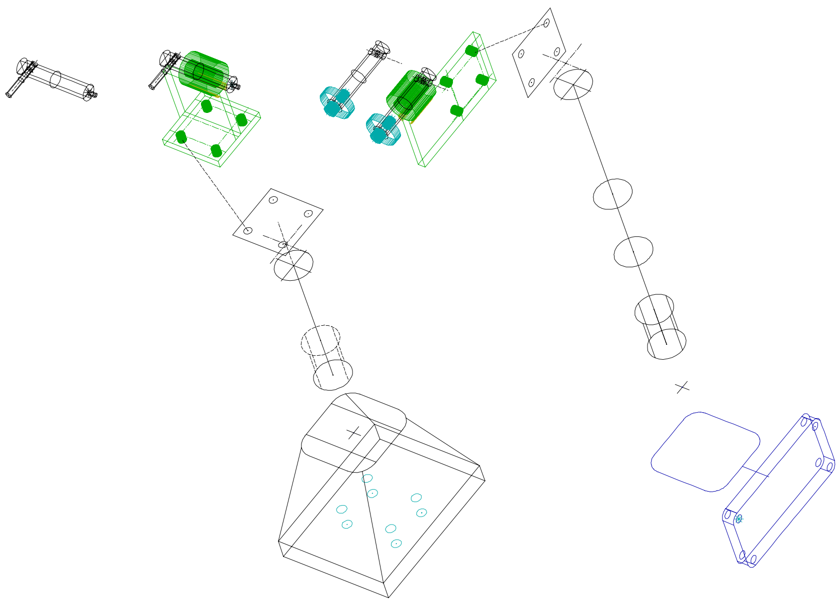


Figure 9.4-2 CAD Data Modules of Fixture System

The DH assembly sequence is exactly the same as it is foreseen in the production plant. Due to the fact that in prototype productions no cycle time limit is given one fixture can be used for more joining operations than in a production line. This results in a drastically reduced number of assembly fixtures in relation to a production line.

For the ULSAB assembly, the Porsche body shop used the following fixtures:

- Assembly Shock Tower Front
- Assembly Front End
- Assembly Floor Complete
- Assembly Under Body Complete
- Assembly Body Side Inner
- Assembly Body Complete

An example of a fixture design is shown in Figure 9.4-3.

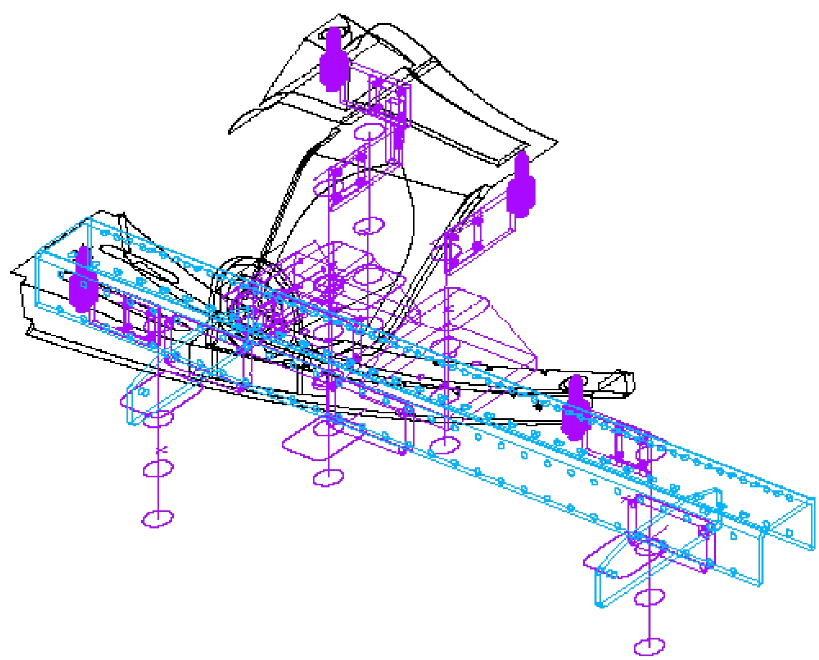


Figure 9.4-3 Fixture Shock Tower Front

9.5. DH Build

9.5.1. Assembly Team

The Porsche BIW assembly team consists of the following personnel:

- 1 foreman
- 1 expert/deputy foreman
- 23 workers which include 5 with foreman's / technician's degree and 5 workers trained for CATIA

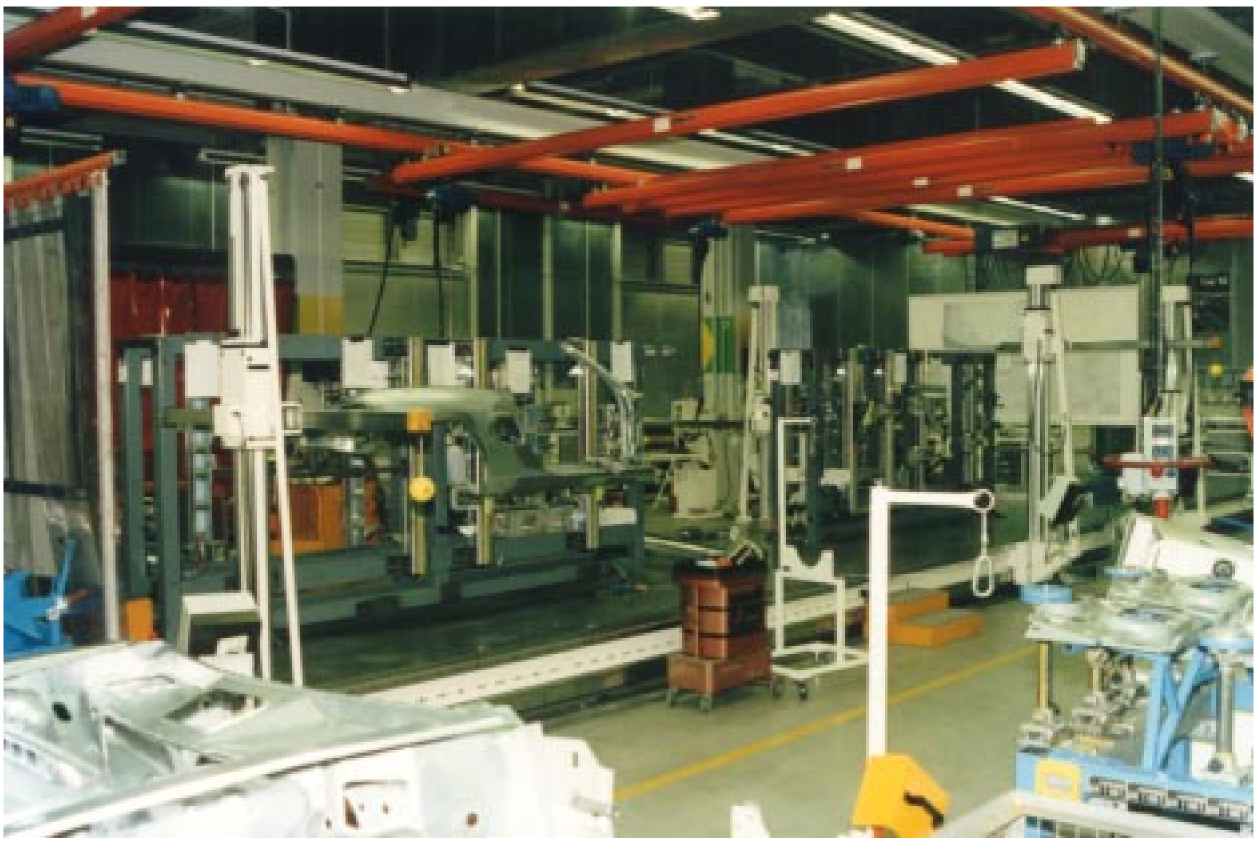


Figure 9.5.1-1 Body Shop

In a workshop space of 1200 m^2, the following equipment is installed:

- 12 setup pallets (6x3m) with surface measuring device
- 4 mobile welding machines, 1000 Hz with control equipment
- 5 mobile welding machines, 50 Hz with constant-voltage regulation system
- 5 overhead spot-welding devices with 3 secondary guns each and a 50 Hz Bosch control system
- 1 Rofin Sinar Laser device, 2.5 kW

Two applications with special interest for ULSAB will be described in more detail.

All spot welds on ULSAB were manufactured with a mobile Duering welding cart and a Matuschek medium-frequency inverter device with master control system.

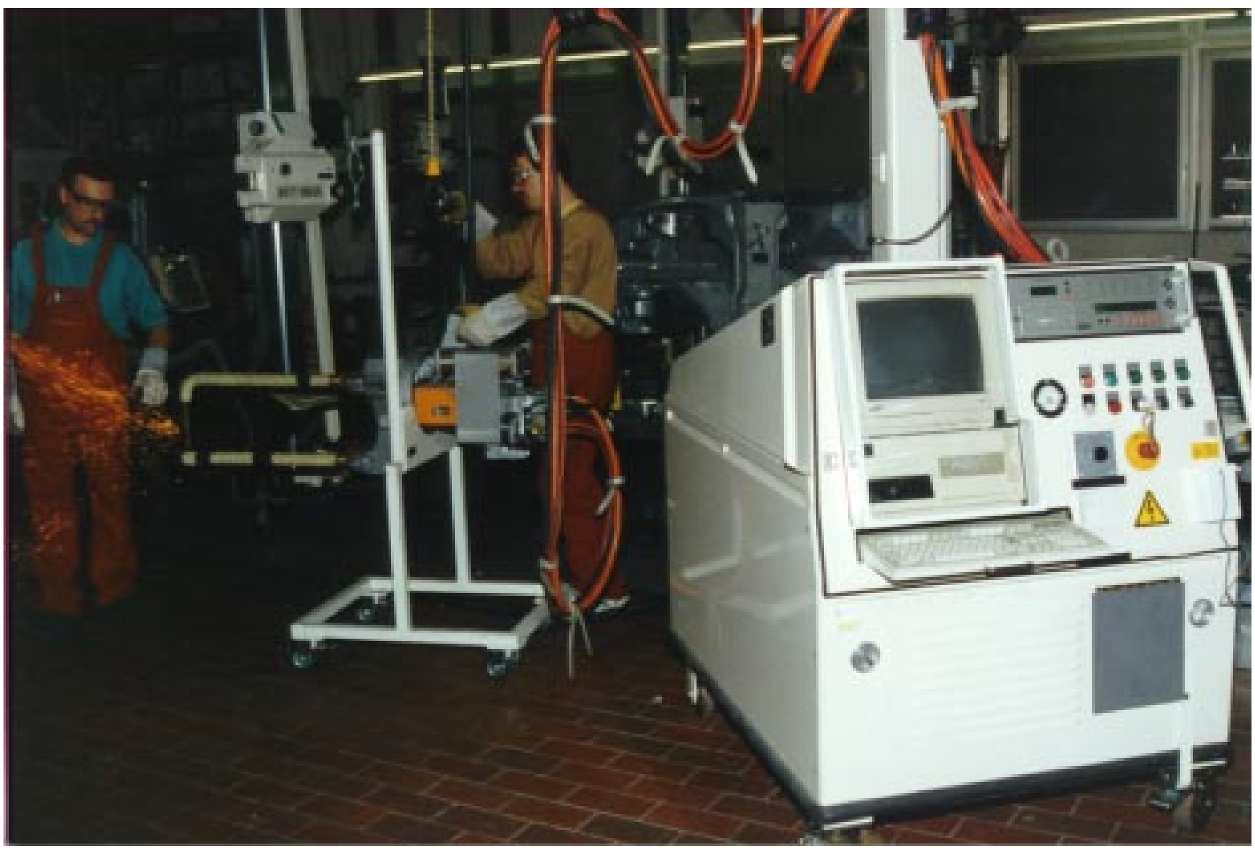


Figure 9.5.1-2

The welding gun changeover system allows a rapid change between different types of welding guns, whereby a special gun coding provides the correct weld parameters from an automatic program selection.

Figure 9.5.1-3 Weld Gun Station

The laser welding and laser cutting cabin is equipped with a KUKA KR 125 robot. The maximal load is 125 kg and the working range of 2410 mm.

Figure 9.5.1-4 Laser Cabin

The laser source is a Rofin Sinar CW 025 Nd:YAG Laser. The maximum output of 2500 W is transferred through a switching device with two outlets via two 15-m glass fibre cable of 0.6 mm diameter to the laser optic.

Figure 9.5.1-5 Laser

Besides a laser cutting head three different types of laser welding heads are available.

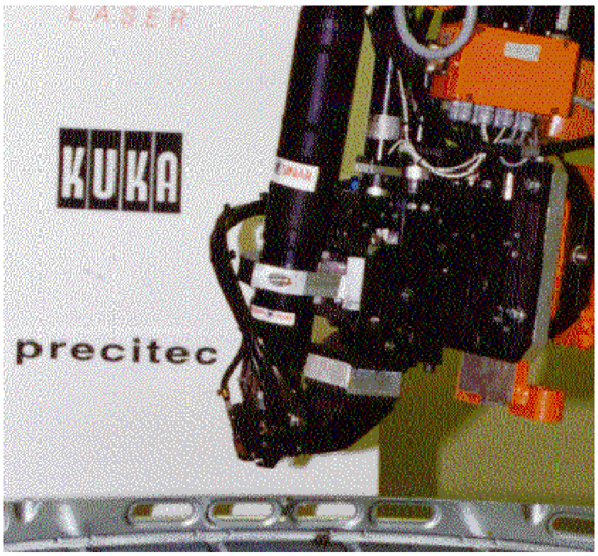


Figure 9.5.1-6 Laser Picker

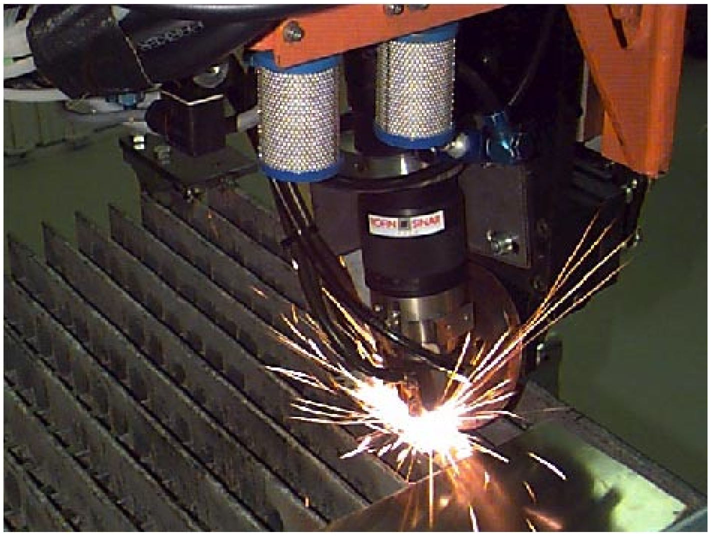


Figure 9.5.1-7 Single Roller

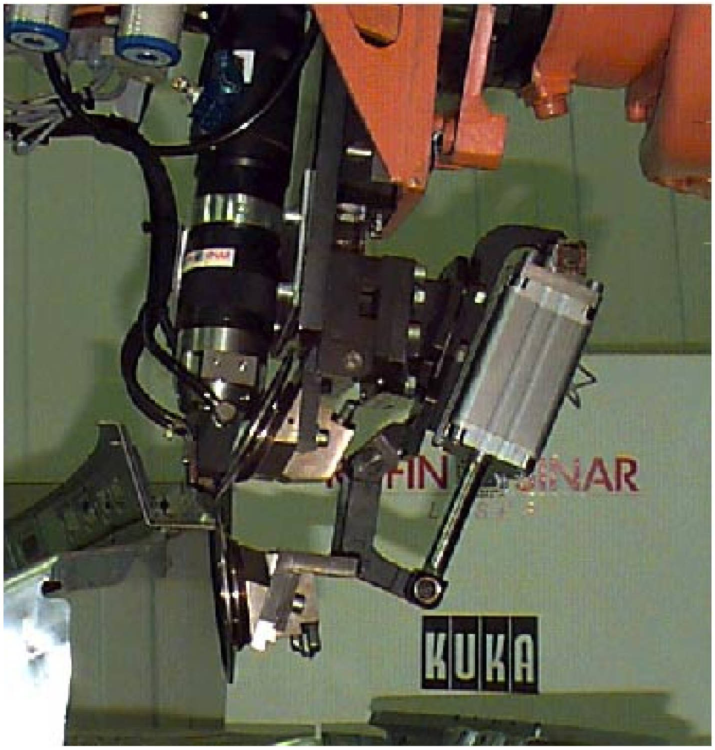


Figure 9.5.1-8 Double Roller

9.5.2. Build of the Test Unit

The construction of the test unit, internally called “workhorse,” started on May 26, 1997, and began testing on June 27, 1997.

The following series of photographs shows steps of the assembly sequence of the test unit.

Due to the extensive preparations, the construction worked out excellent, but there was still room for small improvements.

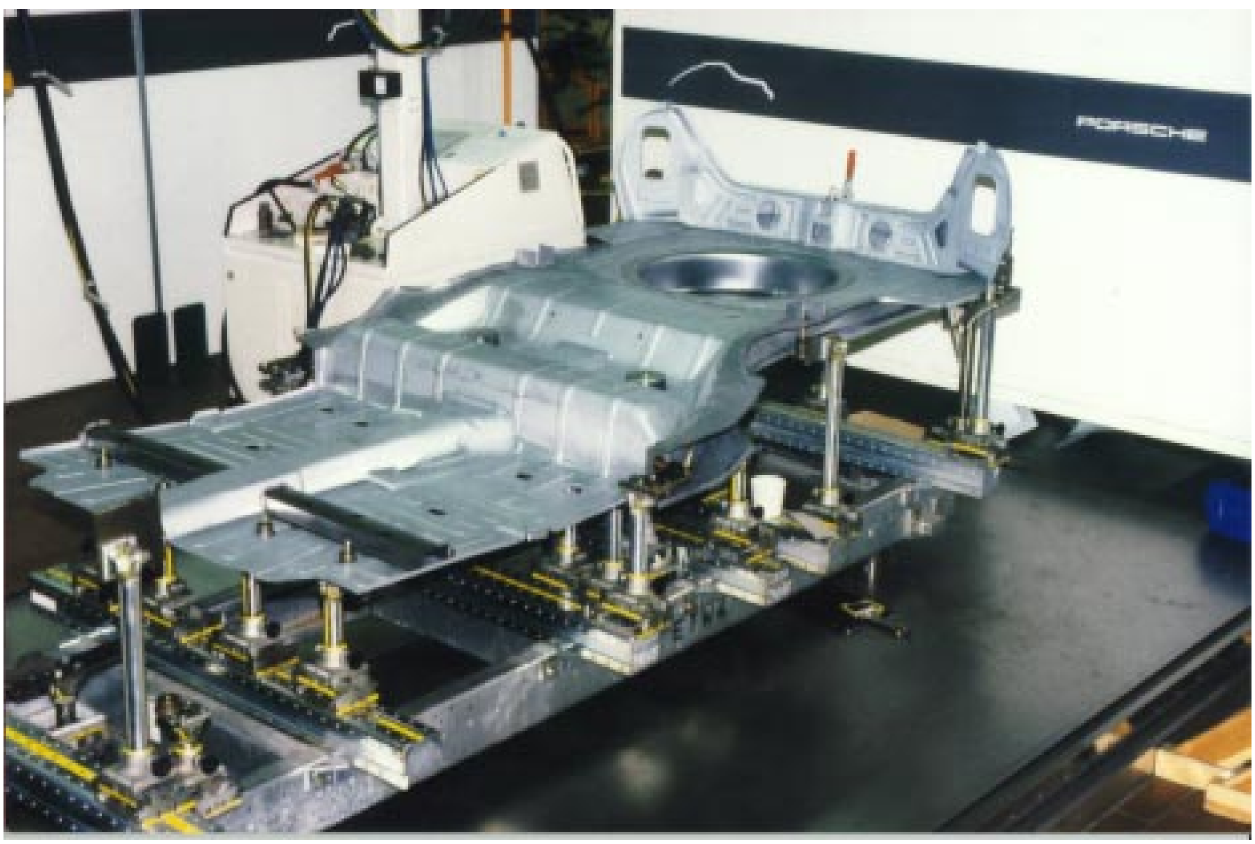


Figure 9.5.2-1 Rear Floor Subassembly

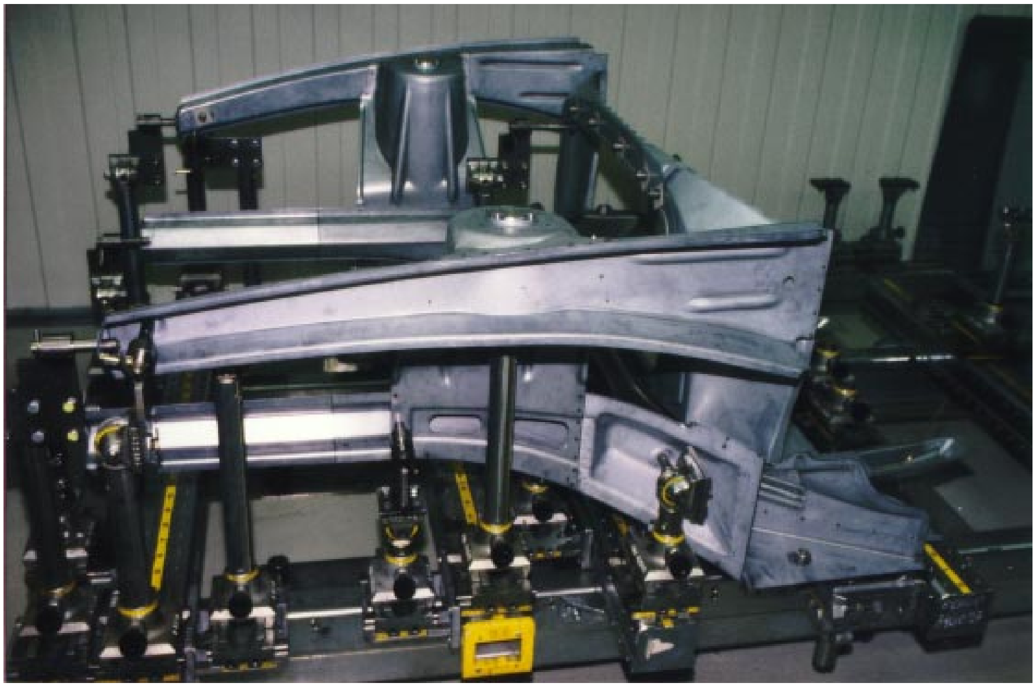


Figure 9.5.2-2 Subassembly Front End

Figure 9.5.2-3 Subassembly Underbody Complete

Figure 9.5.2-4 Subassembly Body Side Inner

Figure 9.5.2-5 Assembly Body Side Inner to Underbody

Figure 9.5.2-6 Subassembly Body Side Inner with Underbody

Figure 9.5.2-7 Sub-Assembly Body Side Outer, with Body Side Inner and Underbody

9.5.3. Build of DH #2 to DH #13

After build and testing of the test unit, a design review meeting in Porsche's R & D Center was held with the experts in the fields of body design, safety, CAE calculations, parts manufacturing and body assembly. Ideas for improvements in respect to performance, parts feasibility, weld access and appearance were generated in this meeting.

The next step was a redesign of the ULSAB body structure reflecting the ideas of the design review meeting. The CAE calculations of the changed FE model proved nearly the same performance. Now new parts were manufactured incorporating these changes in the construction of DH #2 to DH #13.

Figure 9.5.3-1 Demonstration Hardware #2 in Body Shop

The build of DH #2 started on December 1, 1997. The assembly sequence for DH #2 to DH #13 remained the same as test unit.

9.6. Quality

9.6.1. Body Quality Control Team

The Porsche Body Quality Control Team includes the following personnel:

- 1 engineer
- 2 technicians
- 5 foremen
- 2 specialist workers

In a working area of 300 m^2 the following equipment is used for body quality control measurement:

- 1 Stiefelmeyer double-column coordinate measuring machine (CMM)
- 1 Stiefelmeyer single-column manual measuring machine
- 1 Zeiss double-column CMM

Figure 9.6.1-1 DH #2 during Measuring Procedure

The general range of services includes:

- Part acceptance at supplier’s premises
- Model acceptance at supplier’s premises
- Body measurement
- Digitalization of data for design
- Trouble-shooting
- Prototype quality statistics

9.6.2. Quality Control Measurements of DHs

The basis for part and assembly quality was the early involvement of all relevant participants in the design and engineering process. Regularly simultaneous engineering meetings were established with designers, engineers, material suppliers, tool and part manufacturers and body shop personnel.

The expert group defined locator holes, tooling holes and fixing points. To ensure excellent quality, these defined points were used for the complete process chain from parts manufacturing over subassemblies to final assembly.
All manufactured parts were inspected by the supplier’s quality control personnel and approved by Porsche specialists.

The first proof of feasibility and design for manufacture was the successful construction of the test unit. This demonstration hardware was fully inspected by Porsche’s quality control team. In total, about 200 different points on the ULSAB body structure were measured and compared to the original CAD data.

The measured dimensions were, especially for a first time assembled body structure, in a close range to the nominal values.

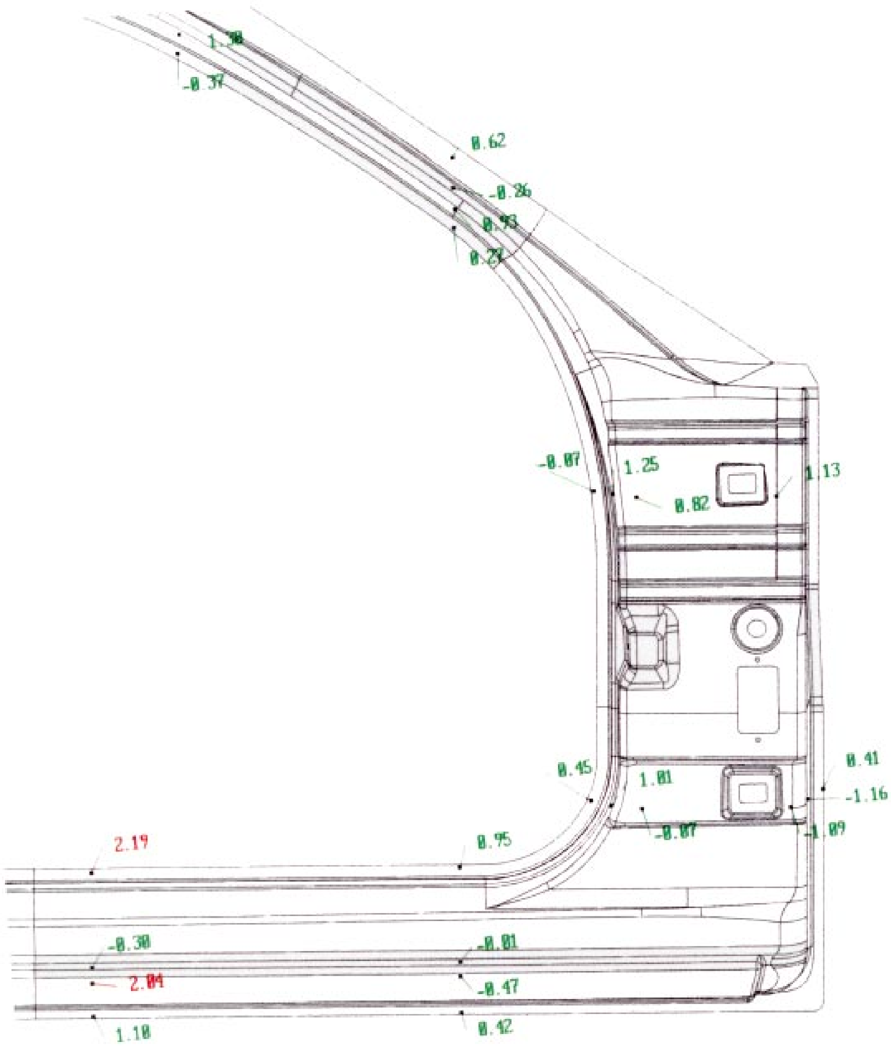


Figure 9.6.2-1 Measuring protocoll

Nevertheless, the results of the test unit were used to develop modifications of the tools for part manufacturing and of the assembly fixtures for improved quality, meaning smaller tolerances for the following DHs. Each DH is or will be inspected to evaluate a quality statistic for the ULSAB program.

9.7. Conclusion

The assembled demonstration hardware proved to be a successful execution of the body structure construction. The measured tolerances are in a comparable range in relation to average car programs.

The challenges of laser welding in assembly, assembly of hydroformed parts, 90% high strength steel, and steel sandwich material, were mastered. The principle condition for success was the simultaneous engineering process. All project partners contributed to the realization of Phase 2 of the ULSAB program.

Through early involvement in the project, all parties involved incorporated all of their expertise into the realization of the demonstration hardware.

Figure 9.7-1