Advanced Computed Tomography System for the Inspection of Large Aluminium Car Bodies

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Abstract. An advanced 3D CT system with the capability to scan parts sizing from 3 mm up to 5000 mm was developed. The newly designed non destructive inspection system overcomes existing limitations of conventional CT systems in terms of part size and resolution. Reconstruction and scan algorithms were developed that allow achieving three-dimensional information of material and geometry in large automotive bodies with a resolution of up to 30 µm. In micro 3D CT mode a resolution of up to 3 µm can be achieved. The development of the mechatronic inspection system includes aspects of mechanics, electronics, software, and algorithms. For the manipulation of the full range of parts a high precision manipulation system and an industrial robot are used. The system allows the car manufacturer to inspect non-destructively a variety of join connections in car body parts. The capability of the system is demonstrated by different applications.

Introduction

In the automotive industry there is a growing demand for non destructive 3D inspection methods. However, destructive testing methods are still state-of-the-art for the inspection of car body parts. AUDI Neckarsulm has been using extensively destructive testing methods for the inspection of joints in car bodies in the past years (***Fig. 1***). These methods provide only limited information since polished sections are two dimensional. Furthermore, in some cases the polishing process changes the structure of the joint. Therefore, a new inspection method was needed with the ability of providing three dimensional information and being non-destructive. This is especially required because there is a tendency of increasing material stressing in combination with growing requirements of safety. Furthermore, the amount of scrap parts from the destructive inspection methods needs to reduced.

Fig. 1: Car body being cut into pieces for destructive testing

As state-of-the-art in industrial X-ray inspection for large objects there are radioscopy systems providing two dimensional projective images. This method does not allow to localise the material features three dimensionally. On the other hand, available 3D X-ray computed tomography systems do not allow to scan large parts in high resolution because of its requirement that the object needs to be fully enclosed by the X-Ray cone in the planes perpendicular to the axis of rotation (***Fig. 2***). Furthermore, 3D reconstruction algorithms require a 360° rotation of the object [1,2]. These limitations do not allow to scan large parts in many cases or lead to a low spatial resolution.

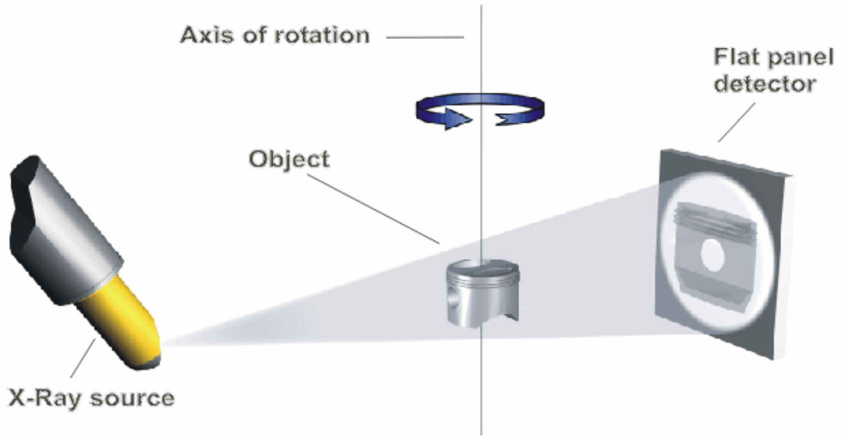

Fig. 2: Conventional 3D computed tomography require the object to be fully enclosed by the X-Ray cone horizontally

We present here a new development of Hans Wälischmiller GmbH that overcomes these limitations. The development includes aspects of mechanics, electronics, software and algorithms.

Requirements and System Concept

The car manufacturer has a variety of techniques for joining car body parts. Among these are MIG welding, laser welding, riveting and glueing. The joining techniques are applied to objects of different size, geometry and material. ***Fig. 3*** shows a selection of parts to be inspected, from sub-assemblies up to the fully assembled car body.

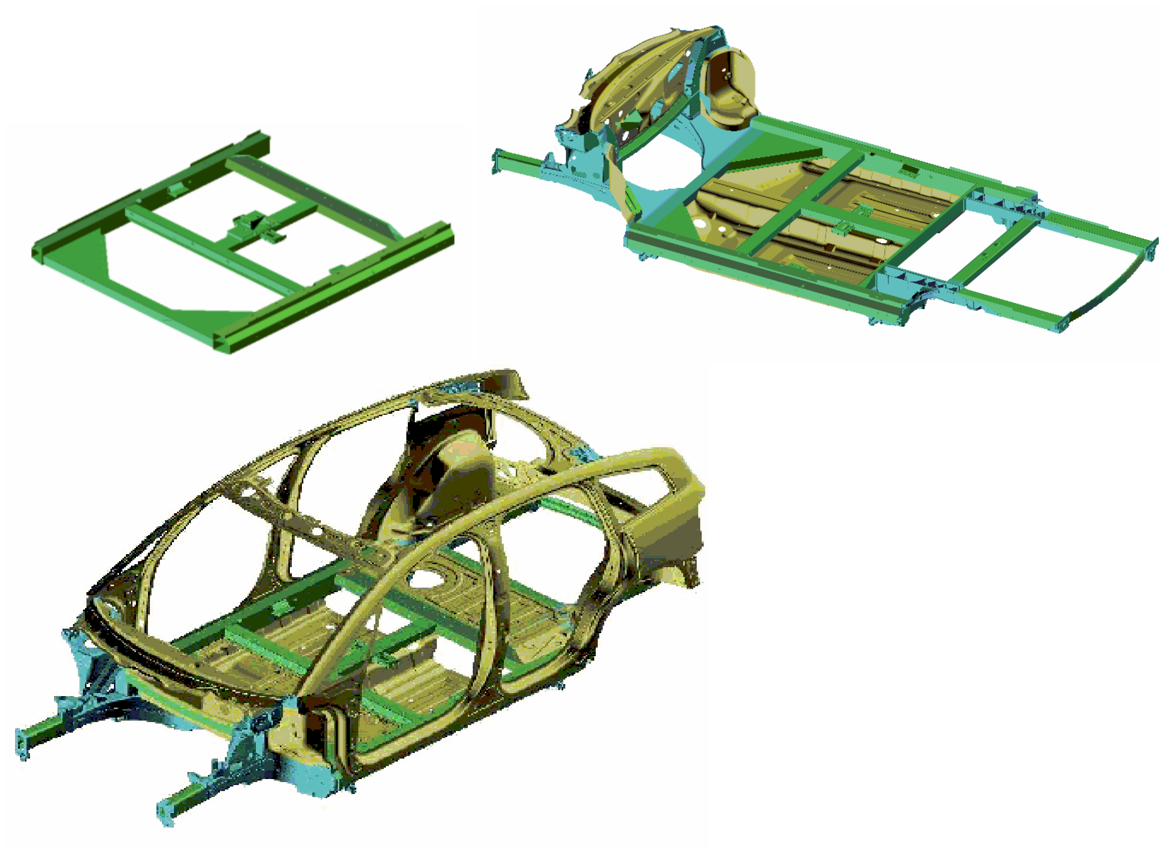

Fig. 3: Car body parts to be inspected: sub-assemblies up to the fully assembled car body

The size of objects range from 3 mm up to 5000 mm. Applying conventional 3D computed tomography to the large parts would lead to a spatial resolution of several mm because of the limitations described in the previous section and in [3]. However, the quality assurance requests a minimum spatial resolution of 50 µm even for the large parts. Based on these requirements a feasibility study was performed in order to find a suitable system concept. The mechatronic process chain of the CT scanner was modelled and extensive simulations were performed to find a solution that overcomes the existing limitations of scanning and reconstruction techniques. The concept is based on two principles, region of interest CT (ROI-CT) and limited angle scanning in combination with a magnifying technique.

The region of interest method allows to project a section of the full object on the detector. Depending on the distances between source, object and detector this section appears magnified at the detector plane. However, in many cases, especially for large objects it is not possible to do a full rotation of 360° because of collisions. Therefore, the region of interest method had to be combined with limited angle scanning.

Besides the new scanning method new reconstruction algorithms had to be developed because the use of standard reconstruction methods lead to strong artefacts. An important part of our development was a combination of simulation and experimental calibration, which enabled us to develop algorithms and procedures that lead to reconstructions with low artefacts. In this way the goal of highly resolved 3D sections inside of large objects was achieved.

System Design

Besides the requirement of scanning large car body parts in high resolution the system is designed for 3D CT including micro 3D CT. Therefore, the system is able to scan parts in a range from 3 mm up to 5000 mm with a resolution of up to 3 µm.

The object handling is based on a CT manipulation system and an industrial robot. Small parts are handled by the CT manipulation system, whereas for the manipulation of voluminous and weighty parts an industrial robot is integrated into the system. The object manipulation in combination with a microfocus x-ray tube, a large area amorphous silicon detector and a sophisticated electronic and software design are the main components of the RayScan 200 XE system. Multiple sensors measuring distance, position, temperature, X-ray dose, etc. are used to integrate the components and to enhance the quality of the system. ***Fig. 4*** shows the parts of the CT system inside of the shielding cabinet.

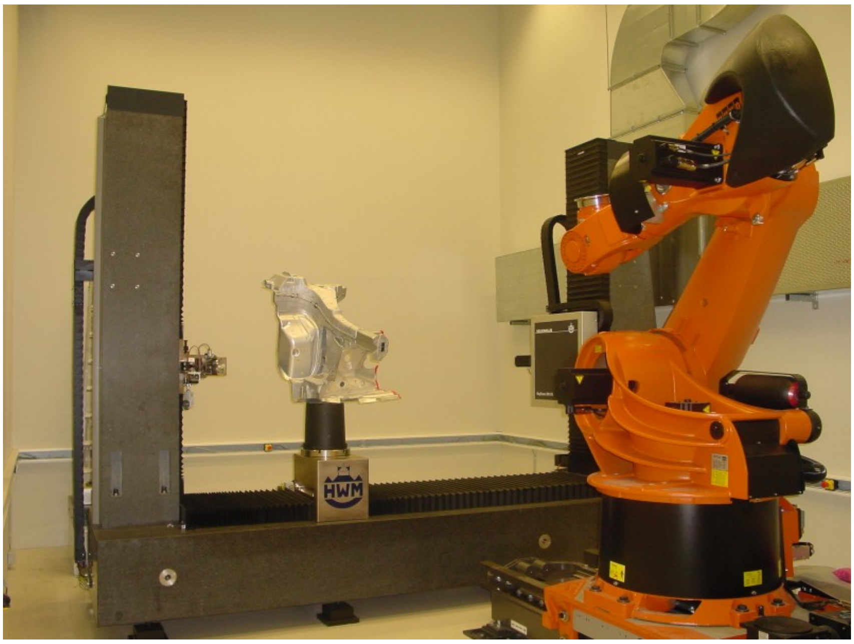

Fig. 4: CT system RayScan 200 XE inside of the shielding cabinet

Highly precise mechanical and electronic components had to be developed in order to achieve high quality results for the whole range of part dimensions. The CT manipulation system was realised by a granite basis with high precision linear guidance systems. Although the system has a total length of 4600 mm, a positioning accuracy of in the range of one micron was achieved.

The CT system with the robot was integrated into a large shielding cabinet with a base area of 9 m * 6 m and a height of 6 m. In this way the full car body can be scanned inside of the shielding cabinet. The system is situated close to the production area where oscillations take place. For this reason vibration measurements were performed and a concept to avoid that oscillations influence the CT measurements was developed. It was found that the most efficient way to damp oscillations was to separate the foundation of the system, comprising of the main components CT scanner with robot and shielding cabinet, from the foundation of the production hall. Vibration absorbers were placed below the foundation to isolate the system with a total weight of 370 tons. Since the entire system is damped, vibrations from outside do not influence the measurements, neither measurement with the object placed on the CT manipulator nor with the object placed on the robot.

The range of part size, different geometries and materials require a flexible scan concept. Depending on the accessibility of the sections to be inspected different scan methods can be used. ***Table 1*** gives an overview of the available scan modes. Small objects up to a size of Ø600 mm can be scanned with the 3D CT method. In the case of larger objects that fit on the turn table of the CT manipulation system or in the case that a section in the object needs to be scanned in high resolution, region of interest CT is applied. If during a rotation a collision with the CT system would occur, the scan angle can be limited to the maximum possible angle. Very large objects like car bodies are handled by the robot. These parts can be scanned in two different ways. If the section of interest is accessible, radioscopy can be applied to gain two dimensional images in high resolution. To gain three dimensional results transversal CT is applied.

Scan mode	**Object handling**	**Max. object weight**	**Max. object size**	**Resolution**
Radioscopy	CT manipulator	80 kg	Ø1500 mm * 3600 mm	3 µm .. 300 µm
3D CT	CT manipulator	80 kg	Ø600 mm * 3600 mm	3 µm .. 300 µm
3D ROI CT	CT manipulator	80 kg	Ø1500 mm * 3600 mm	10 µm .. 300 µm
Radioscopy	Robot	500 kg	5000 * 2000 * 1500 mm^3	10 µm .. 300 µm
3D transversal CT	Robot	500 kg	5000 * 2000 * 1500 mm^3	30 µm .. 300 µm

Table 1: *Scan modes of the RayScan 200 XE system*

The variety of scan modes allows the operator to find in most cases a suitable method to inspect the joints in high resolution. Examples will be given from the inspection of different joining techniques like weld joints, riveted joints and glued joints.

Results

A selection of results from the large range of part size, material and joining techniques is presented in this section to demonstrate the potential of the system and its benefit for quality control. In ***Fig. 5*** a summary of the spectrum of parts is shown. A micro switch is scanned with micro 3D CT, for the car door region of interest CT is applied and the car body is handled by the robot and scanned with transversal CT.

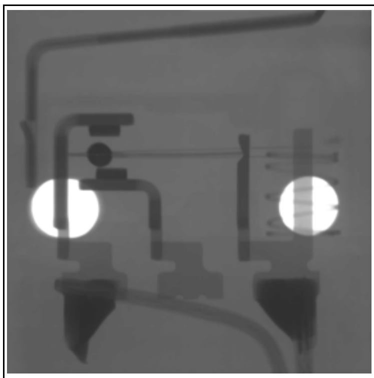	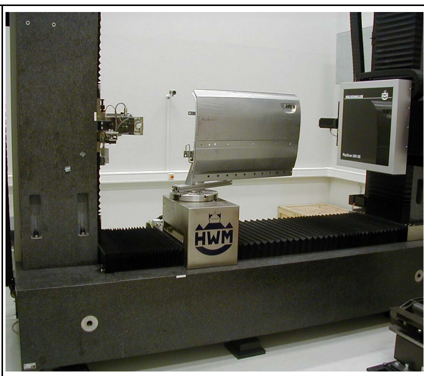	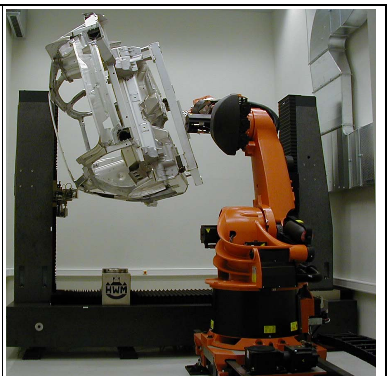
Micro switch, size: 10 mm	Car door AUDI A8, size: 1150 mm	Car body AUDI A8: 4770 mm

Fig. 5: Spectrum of parts to be inspected with the CT system

The inspection of a glued joint of a car body is shown in ***Fig. 6***. The section of the glued joint is shown in the photograph on the left side. A comparison between micro radioscopy and destructive testing is shown on the right side. The distribution of glue is clearly visible and the quality of the joint can be evaluated. Small differences are due to the fact that the destructive testing removes a part of the glue.

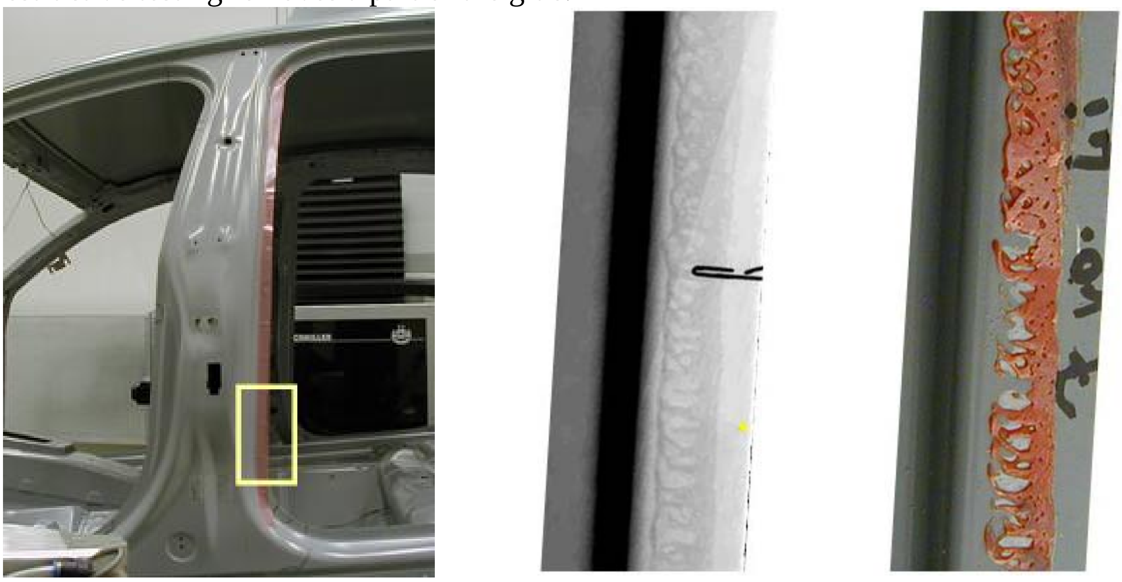

Fig. 6: Micro radioscopy of a structural glued joint of a car body

If the glued joint is embedded in a more complex structure, radioscopy does not reveal sufficiently the three dimensional structure. In this case 3D CT can be applied. ***Fig. 7*** shows a 3D CT of a folded seam connection. The part was prepared for verification purposes. Two virtual slices reveal the two materials aluminium and polymer in two grey values. The cavities can be analysed two dimensionally in the virtual slices and three dimensionally in the 3D visualisation.

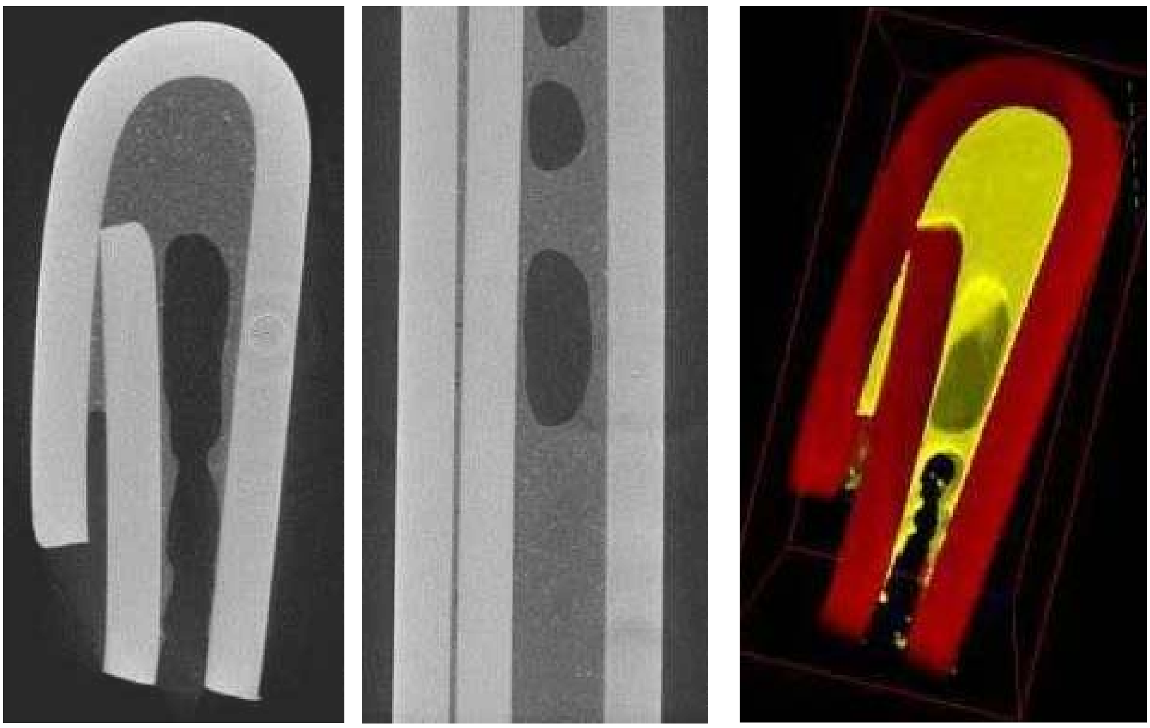

Fig. 7: 3D CT of a glued folded seam connection

Another application of 3D CT is aluminium laser welds. In ***Fig. 8*** the 3D visualisation with a virtual cut is shown on the left side. A crack and a cavity is visible. Also the 2D slice on the right side reveals a crack and several cavities.

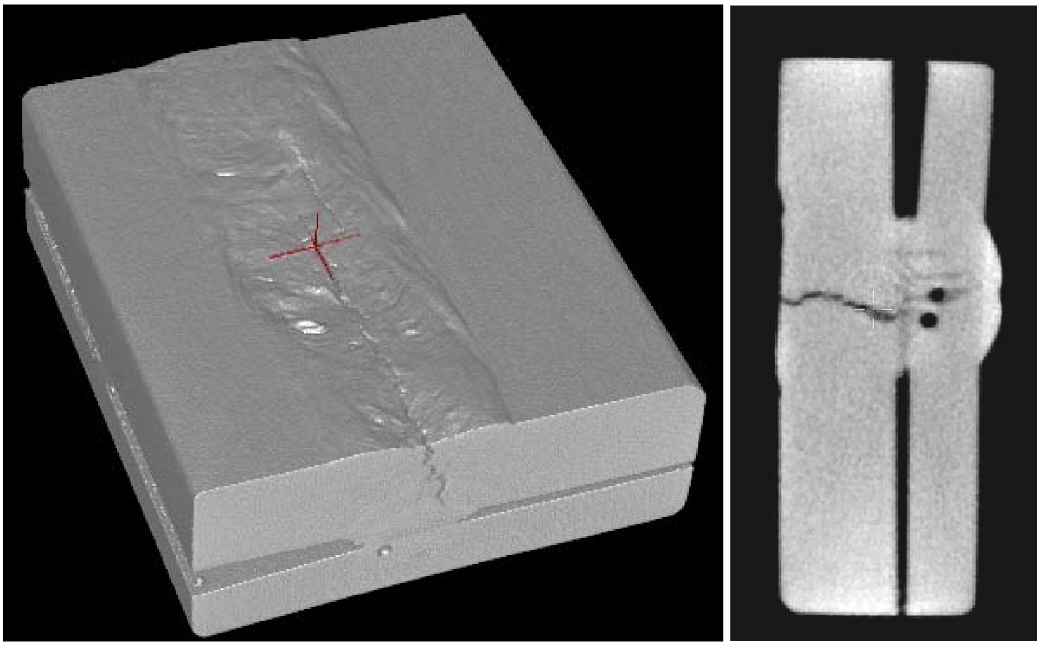

Fig. 8: 3D CT of an aluminium laser weld

Subassemblies are usually too large for 3D CT scans. The region of interest CT as described above was applied to a MIG welded aluminium frame (***Fig. 9***). In ***Fig. 10*** the 3D visualisation and a virtual slice through the welding (upper yellow circle in ***Fig. 9***) is shown. The scan reveals the root penetration and a cavity. A region of interest CT of a MIG welding between two extruded profiles (lower blue circle in ***Fig. 9***) was performed. The result is shown in ***Fig. 11***. Small pores are visible as black spots, white spots show inclusions which were found to be steel particles.

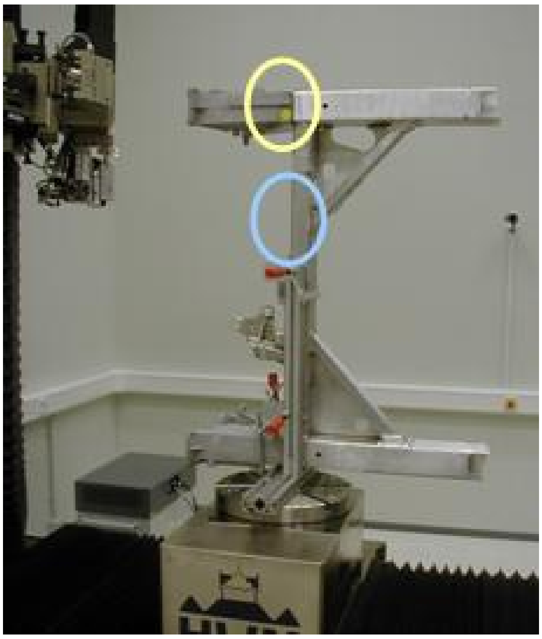

Fig. 9: MIG welded aluminium frame

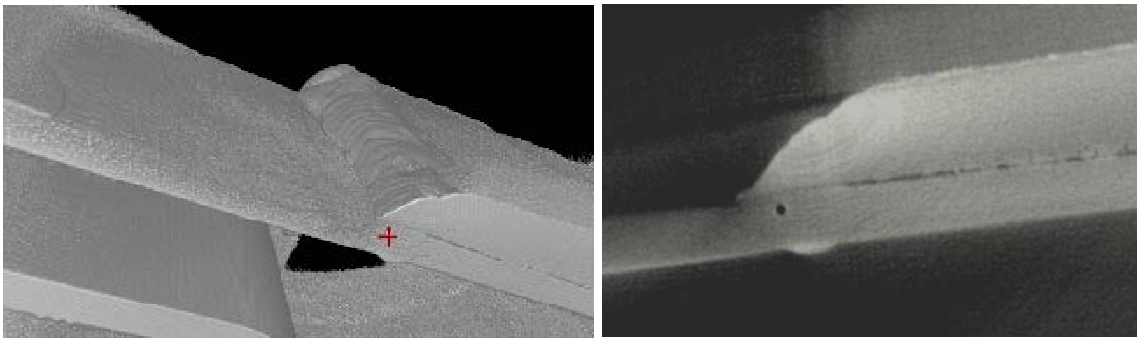

Fig. 10: ROI CT of a MIG welding between casting and extruded profile (yellow circle)

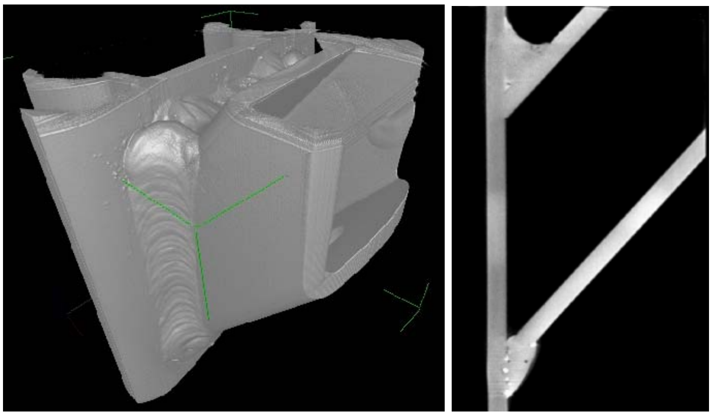

Fig. 11: ROI CT of a MIG welding between two extruded profiles (blue circle)

Large parts like the fully assembled car body are handled by the robot and scanned in transversal CT mode. An example of the robot handling is shown in ***Fig. 5***. The rectangle shown in ***Fig. 12*** indicates the scan area. In ***Fig. 13*** the 3D visualisation and the virtual slice at the right side shows a cut through the welding without defects.

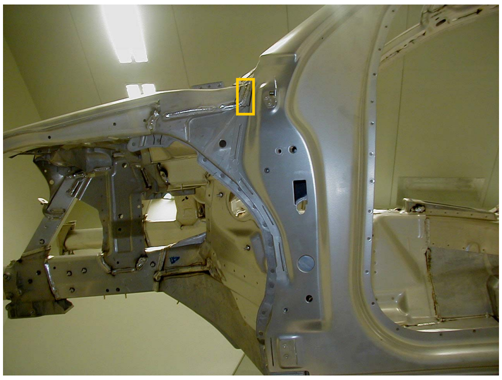

Fig. 12: Car body during a transversal CT measurement of a MIG welding

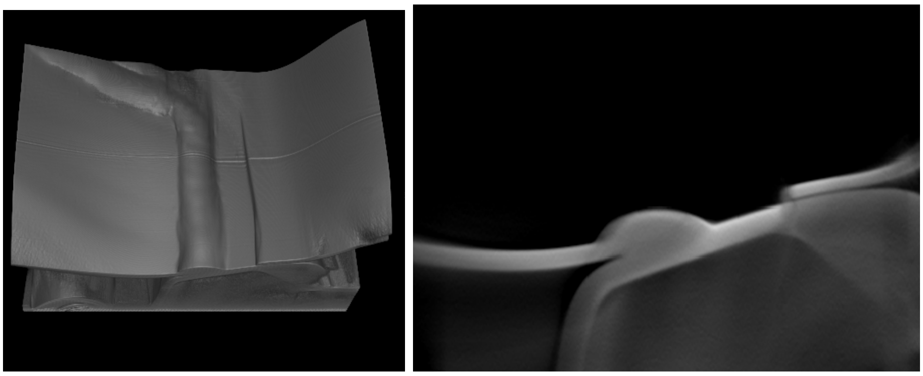

Fig. 13: Transversal CT of a MIG welding at a car body

A rivet joint virtually extraxted from the car body is shown in ***Fig. 14***. The 3D visualisation reveals the three dimensional deformation and the virtual slice shows a crack at the edge of the rivet.

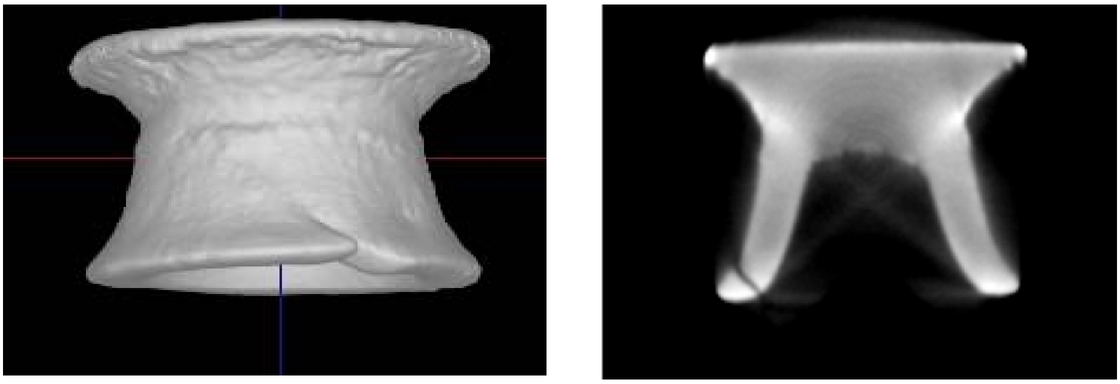

Fig. 14: Rivet joint extracted from a car body

Conclusions

A new advanced multi-scan and multi-sensor computed tomography system for the inspection of large aluminium car bodies was developed and successfully applied. Besides 3D CT and micro 3D CT the system includes newly developed extended scan methods which allow to scan small sections inside of large objects up to a size of car bodies. A varienty of different scan methods in combination with the handling by a robot leads to a highly flexible system that is able to provide three dimensional information for objects sizing from 3 mm up to 5000 mm. All the basic joining techniques like welding, glueing and riveting can be inspected non destructively. The ability to analyse joints and its defects in high resolution was proven by different application examples. Besides providing valueable three dimensional information the system is able to reduce the amount of scrap parts produced by destructive testing methods.

References

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[3] M. Simon, C. Sauerwein, and I. Tiseanu: Extended 3D-CT Method for the Inspection of Large Components. Proceedings of the 16th World Conference on Nondestructive Testing, Montréal, Canada Aug. 30 – Sept. 3, 2004