Robot-based 3D waterjet cutting – an environmentally sound technology

The German carmaker BMW employs waterjet cutting in the manufacture of its instrument panels on account of the excellent economy and future-oriented platform it offers for component production. BMW's use of this method underscores the importance being accorded today to this relatively new technology, which is largely the result of development work carried out by ABB I-R Robotized Waterjet, a joint venture set up by Asea Brown Boveri and Ingersoll-Rand. ABB I-R is the market leader in waterjet cutting equipment for three-dimensional applications, and to date the company has installed more than 250 systems worldwide.

Waterjet cutting can trace its origins back to 1975, when it was introduced to produce wooden puzzles. The waterjet cutting machine that was developed replaced a method in which saws were used to cut out the individual pieces. Besides working with a higher precision, the new method also produced less dust.

Early applications were limited

For many years waterjet technology was used only for marginal applications, for example to cut deep-frozen products and ice-cream. In time, however, as the versatility of the method was recognized, so-called waterjet job-shops were set up. The technology employed in these shops was almost exclusively 2D or 2.5D, abrasive being added to the water whenever harder materials had to be cut. At ABB I-R Robotized Waterjet work concentrated mainly on 3D cutting, with ABB I-R in Friedberg, Germany, developing the system further in the robot-based area. In the meantime, the company is a world leader in this important market sector.

Waterjet cutting normally competes in the market with traditional punching and not with sawing or other cutting methods such as laser or plasma cutting. The main advantage of waterjet cutting is that, unlike punching, it does not require a special tool for each workpiece.

The first systems for producing parts with three-dimensional shapes were developed in 1985. Computer-controlled waterjet robots were used first by suppliers to the automotive industry, who employed them to cut roof linings for cars. In the following years the automotive industry and its suppliers installed further systems to cut the floor carpeting and other interior linings. Today, waterjet systems have practically replaced punching and mechanical methods for this work. This is because the punching tools needed for complex shapes are highly complicated, making them very expensive. Worst of all, they are completely inflexible and have to be rebuilt every time changes are made to the shapes of the workpieces.

Stefan Dreyer
ABB I-R Robotized Waterjet

Abrasive waterjets for steel and aluminium

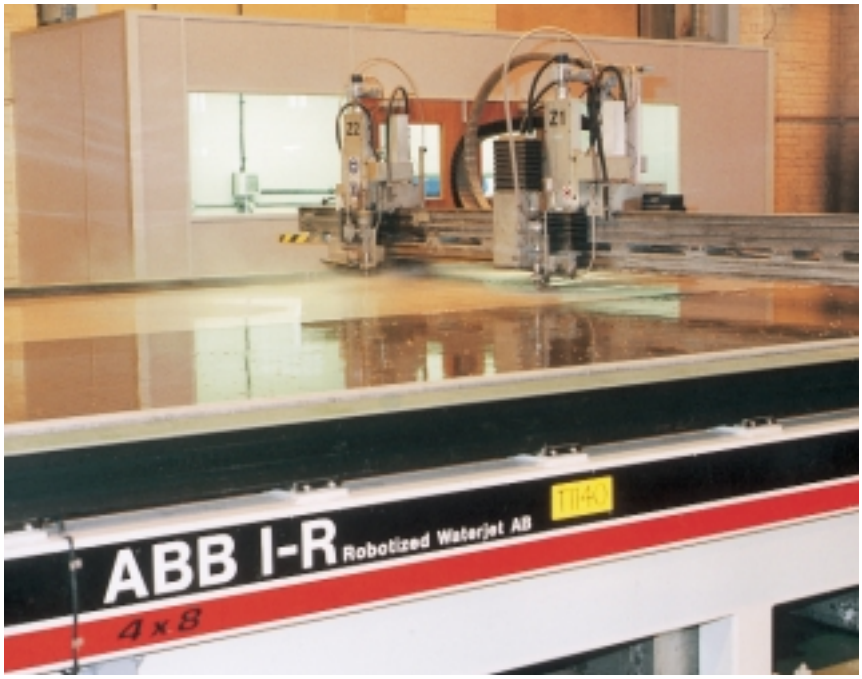
Waterjet technology can be used to cut virtually every material, even steel and aluminium. For example, Crane Fruehauf Ltd in Norfolk, UK, uses large abrasive waterjet cutting tables **1** to produce the cylindrical containers for road tankers. Due to the high energy of the abrasive water jet, thicker aluminium and steel plates can be cut than with laser or plasma cutting technology. Also, waterjet cutting is a generally more robust method, being insensitive to disturbances such as the vibrations caused by other metal-forming processes.

Another important advantage is that, unlike laser or plasma cutting, waterjet cutting does not cause more than minimal heating of the parts. With laser and plasma cutting, the heat that is developed affects the cut edges, which require further work before the parts can be welded. The post-production costs are saved when waterjet cutting is used.

Thanks to waterjet cutting, Crane Fruehauf is able to cut a large variety of different-sized materials. With the help of the computer control, the installed system is also easily capable of cutting holes in sheet metal, for example for the pressure valves in the tank. As a rule, the system is used to cut 3-mm-thick stainless steel and structural steel at a rate of 600 mm per minute.

Plastics, composites and sandwich materials

More commonly, waterjet technology is used to cut plastics and composites,

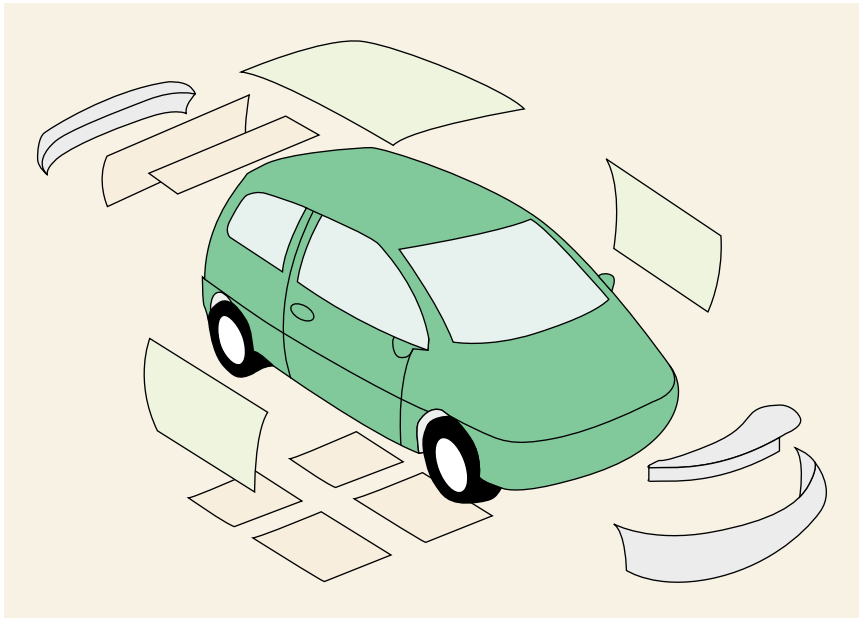


A 3-D waterjet cutting system at Crane Fruehauf Ltd in the UK is used to cut 3-mm thick stainless steel and structural steel at a rate of 600 mm/min. **1**

especially fiber composites, laminated sandwich structures, glass-fiber reinforced and wood-fiber-based composites. Oscillating cutting methods or conventional machining cannot be used for these materials for quality reasons alone.

Many of the parts that make up the interior of modern passenger cars are produced today using waterjet cutting, for example the roof, door and boot linings, rear shelves, carpets, instrument panels and bumpers [1] **2**.

Waterjet cutting is used in the manufacture of numerous interior parts of motor vehicles. **2**



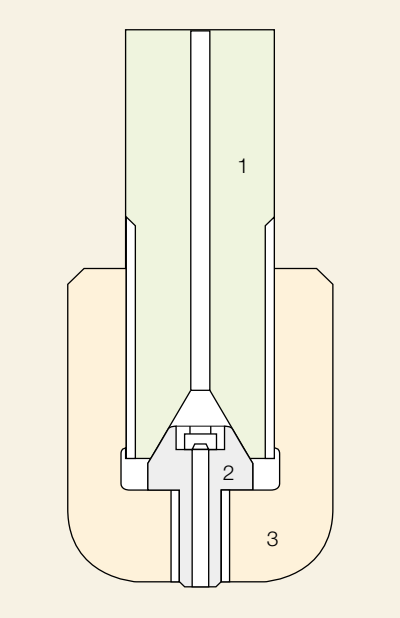
Waterjet tools cut with high precision. The main characteristics and benefits of three-dimensional waterjet cutting are summarized below:

- Well-suited for cutting parts made of composite materials and textile- or fiber-glass-reinforced materials.
- Minimal heat development.
- No dust, smells or smoke produced in the workplace.
- Surfaces of the cuts are of a high quality.
- Cutting forces are low.
- Only simple workpiece fixtures are needed.
- The tool is always sharp as there is no wear.
- Tool radius <0.15 mm, allowing sharp-edged contours to be cut.

Working pressures of 3,000 to 4,000 bar

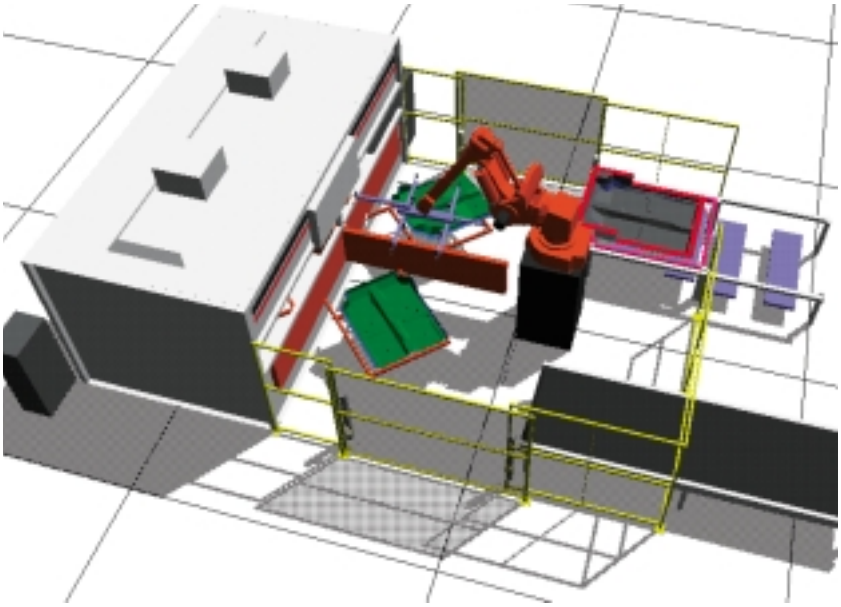
Installed in the cutting box is an electrically driven hydraulic pump that drives a high-pressure unit. A conventional hydraulic system with a power input of 20 to 40 kW provides the driving force for one or more double-acting pressure boosters which produce the required pressure in the water jet. The working pressure lies between 3,000 and 4,000 bar, depending on the application. Nozzles made of sapphire, diamond or very hard metals, with a diameter of 0.1 to 0.5 mm, create a very thin water jet **3**. Hard-metal nozzles are needed when abrasives are added to the water. The maximum distance between the nozzle and the surface of the material being cut is about 50 mm. After it has cut through the workpiece, the jet turns into a spray and immediately loses its cutting ability.

A considerable amount of noise is emitted during waterjet cutting. For a system pressure of 3,500 bar and nozzle diameter of 0.5 mm, the velocity of the waterjet is about 800 m/s, or about three times the speed of sound. A noise level of 110 to 120 dB(A) is generated as a result.



Basic design of the waterjet cutting nozzle **3**

1 *High-pressure pipe*
2 *Sapphire nozzle*
3 *Screwed cap*



CAD animation allows systems envisaged by a customer to be shown in three dimensions on a computer screen, allowing technical evaluations and the fixing of cycle times. **5**

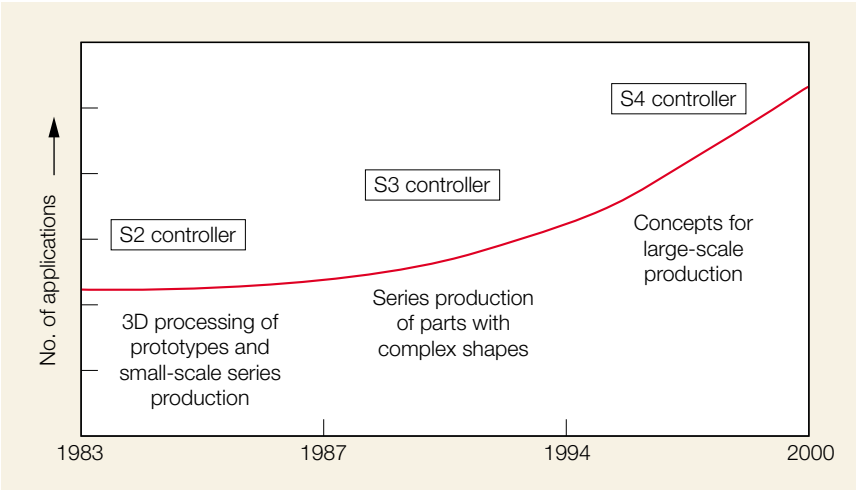
The robots are modified for waterjet cutting by proofing them against a wet environment. The high-pressure pipes are wound in coils around the robot axes to provide elastic compensation for changes in angle and twisting of the robot's wrists. **4**

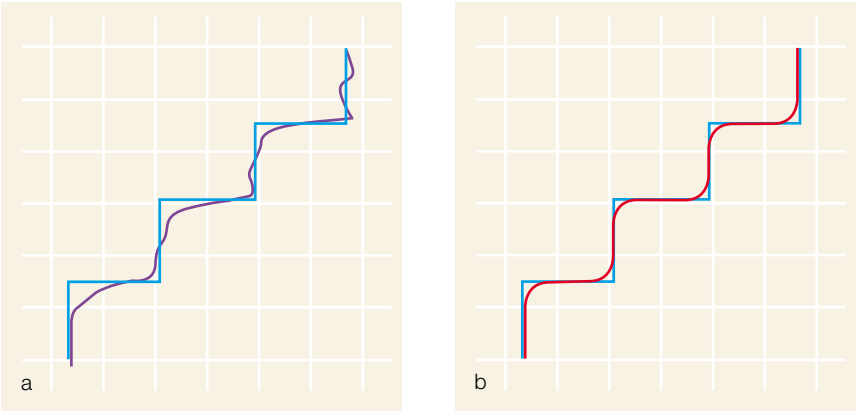
Because of the risk of physical injury, manual manipulation of the water jet is not allowed. Waterjet cutting tools in 2D-installations are guided by AC-driven linear units. ABB industrial robots for 3D installations allow optimum control of the water jet. For example, a six-axis robot can manipulate the nozzle in any required direction whilst ensuring the right cutting angle. The waterjet nozzle is moved along either linear or spherically curved paths at high speed and with very good repeatability.

Robots are modified for waterjet cutting

The robots used for waterjet cutting are not a standard, series-manufactured type, but are modified especially for a wet work-

How further development of the robot controllers has influenced the number of applications and waterjet cutting systems installed **6**





Example of the high quality and cutting precision with the S4 controller, compared with a conventional robot controller (a). The example is for a robot following a curve pattern at 450 mm/s (curve radius 20 mm). 7

ing environment. Among their features are specially designed high-pressure piping, including a design modification which has reliably solved the problems caused by the rotation of the robots' wrists. This involves the pipes being wound in a coil around the axes 4 to provide elastic compensation for changes in angle and twisting of the wrists. Another special advantage is that the robots are suspended from a gantry in the cutting boxes. This not only gives more working space than boxes with floor-mounted robots but also ensures that the robots remain relatively dry, since they do not stand in the water.

The robots used for waterjet cutting are from ABB's new IRB 2400 product line. This robot generation is equipped with the new S4 controller [2], allowing much faster traversing speeds and better path-following accuracy. Even the smallest holes can be cut with high precision and at high speed with this robot.

The six-axis IRB 2400 is a user-friendly robot which is both rugged and slim. It has been designed for easy access to all of its parts as well as for suspension from a gantry. Being middle-sized, the robot is ideal for a wide range of applications. It can handle loads of up to 10 kg and has a large work envelope. For example, when the IRB 2400 is suspended from a gantry the work envelope is 3 m. Handling of the workpieces is also made easier by the simpler transportation of parts that this allows. The robot is designed with the rigidity and balance necessary to guarantee smooth motion throughout the work envelope. TrueMove functions incorporated in the controller guarantee highest precision and repeatability for all positions and paths at all robot speeds. The result is consistently high quality, plus minimal scrap. The IRB 2400 is also extremely easy to use. Staff learn quickly how to operate the robot, thanks to a programming unit that makes use of windows for the system communication. Messages in plain text and easy-to-use function keys support the operator in operating the robots as well as in monitoring production.

Waterjet cutting is also environmentally sound. The particles that are removed during cutting are washed out with the water and are collected by filter systems before the water passes into the public sewerage system. Recycling of the process water is not necessary and would be unprofitable due to the small amounts involved (an average of 1.5 l/min water per nozzle).

'Lean' concept for cutting small plastics parts based on the 'Cutting Box Small Part'. Full utilization is made of the limited space by inclining the rotary worktable. 8

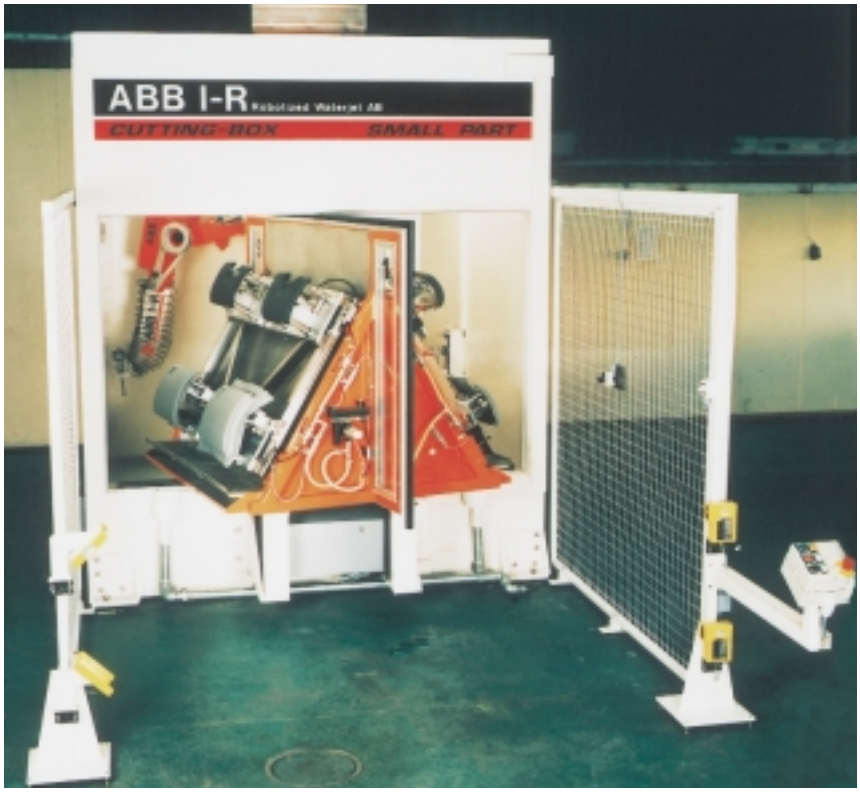


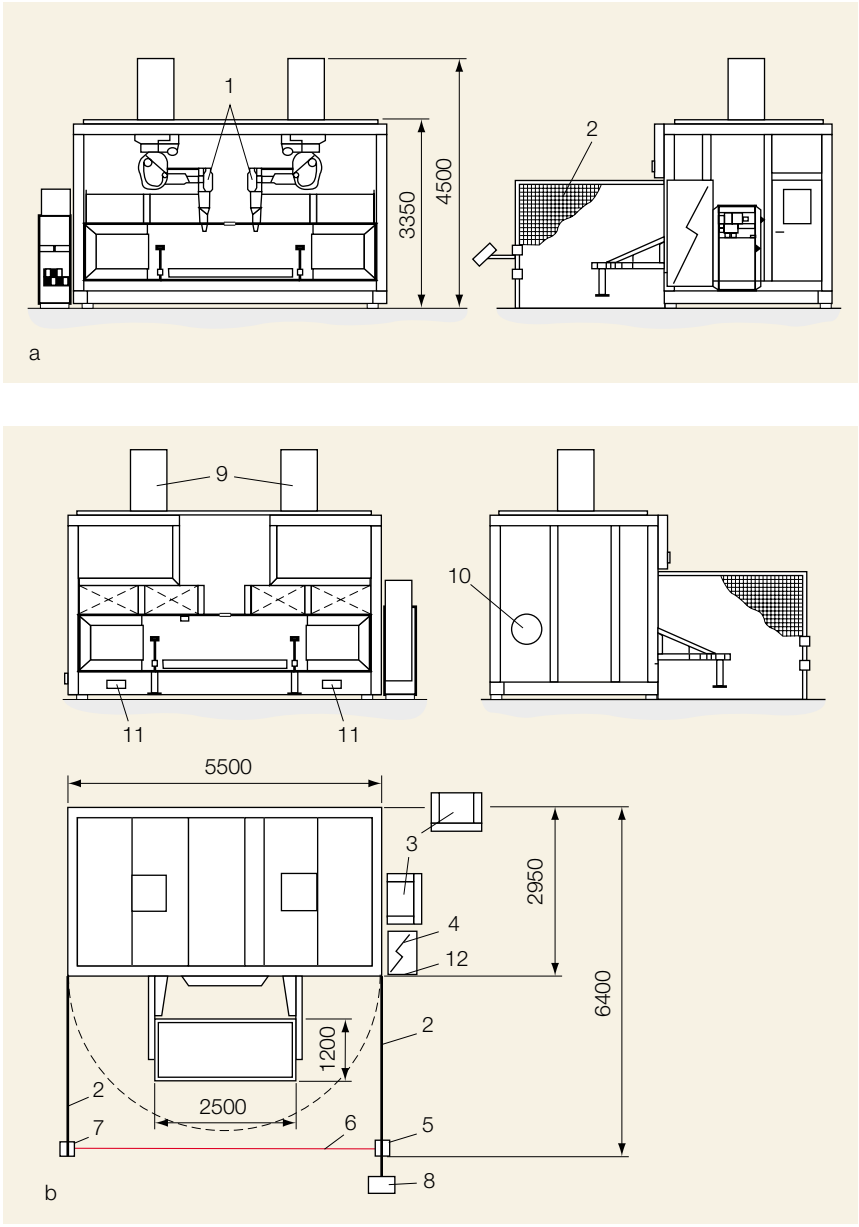
ABB supplies complete production centers

ABB I-R designs and builds complete production centers, including the conveyor systems for large-volume parts transfer. The customized designs are based on proven components from ABB as well as ABB industrial robots and high-pressure pumps from Ingersoll-Rand. Economically priced, custom-built solutions are possible thanks to the modular system design.

Waterjet cutting systems from ABB I-R are built around cutting boxes that form the basis for different production modules. The modules depend on the size of the workpieces, the method used for transportation and how the installations are interlinked.

Design features of the cutting boxes include:

- Flexible cell configurations
- High availability, thanks to standardized components
- Customized designs based on standard parts
- Integrated protection for a high level of safety
- Possibility of integration in existing production lines
- Optimum protection provided for mechanical parts
- High-pressure parts adapted for robot applications
- User-friendly, ergonomic design
- Compliance with ISO and CE directives/standards



'Cutting Box Original' with two IRB 2400 robots. All the different types of cutting box are built around this basic design. 9

a *Without rear wall*
b *With rear wall*

1 *ABB industrial robot, IRB 2400*
2 *Protective mesh*
3 *S4 control cabinet*
4 *Cabinet with PLC*
5 *Light barrier transmitter*
6 *Light barrier*
7 *Light barrier reflector*
8 *Control desk*
9 *Air intake mufflers*
10 *Connecting flange for air-extraction*
11 *Water drain*
12 *Compressed air connection*

Technical evaluations based on CAD animation

To speed up the design, construction and installation of customized, robot-based systems, ABB I-R has developed a method for the CAD animation of waterjet cutting projects. It enables systems that only exist on drawings or in a customer's mind to be shown in detail on a computer screen 5. The design of the installation, cutting tools and robots are simulated to allow a detailed evaluation of the overall system. All preliminary studies, such as technical analyses and the determination of risk of collision, can be carried out at an early stage. In addition, cycle times can be fixed and the operating times of the individual robots can be harmonized.

CAD animation allows simultaneous engineering, ie the robots can be programmed in parallel with the actual con-

struction of the system. This saves a considerable amount of time when commissioning the system. CAD animation also enables the robot programs of systems already installed to be easily rewritten for new or modified products. As a result of this, only minimal fine-tuning has to be carried out locally. Customers only have to provide the CAD data for the new product. The new cutting program can then be written off-line, and afterwards optimized by the user in his own installation.

Path-following is ten times faster with the S4 controller

One of the driving forces behind the development of waterjet cutting has been the steady progress made in the control area 6. The start was made in 1983 with the S2 controller, which already then was equipped for three-dimensional cutting of prototypes and for small-scale series production. The S3 controller, which could also be used for the series production of parts with complex shapes, followed in 1987. 1994 saw the introduction of the new S4 controller, which is also designed for large-scale production.

High-quality cutting as well as greater precision are possible with the S4 controller thanks to path-following being up to 10 times faster and cycle times being 25 percent shorter. The high-speed processor integrated in the robot control makes this possible. As a result, the time needed to optimize the motion is reduced by up to 50 percent 7. With the S4 controller, hole diameters <10 mm can be cut without any reduction in the operating speed. Other key benefits are a programming interface which uses windows for the input and optimization, future-oriented user-specific software, and an advanced hardware platform. Software developed especially for training simplifies learning and provides a user-friendly introduction to the S4 controller.

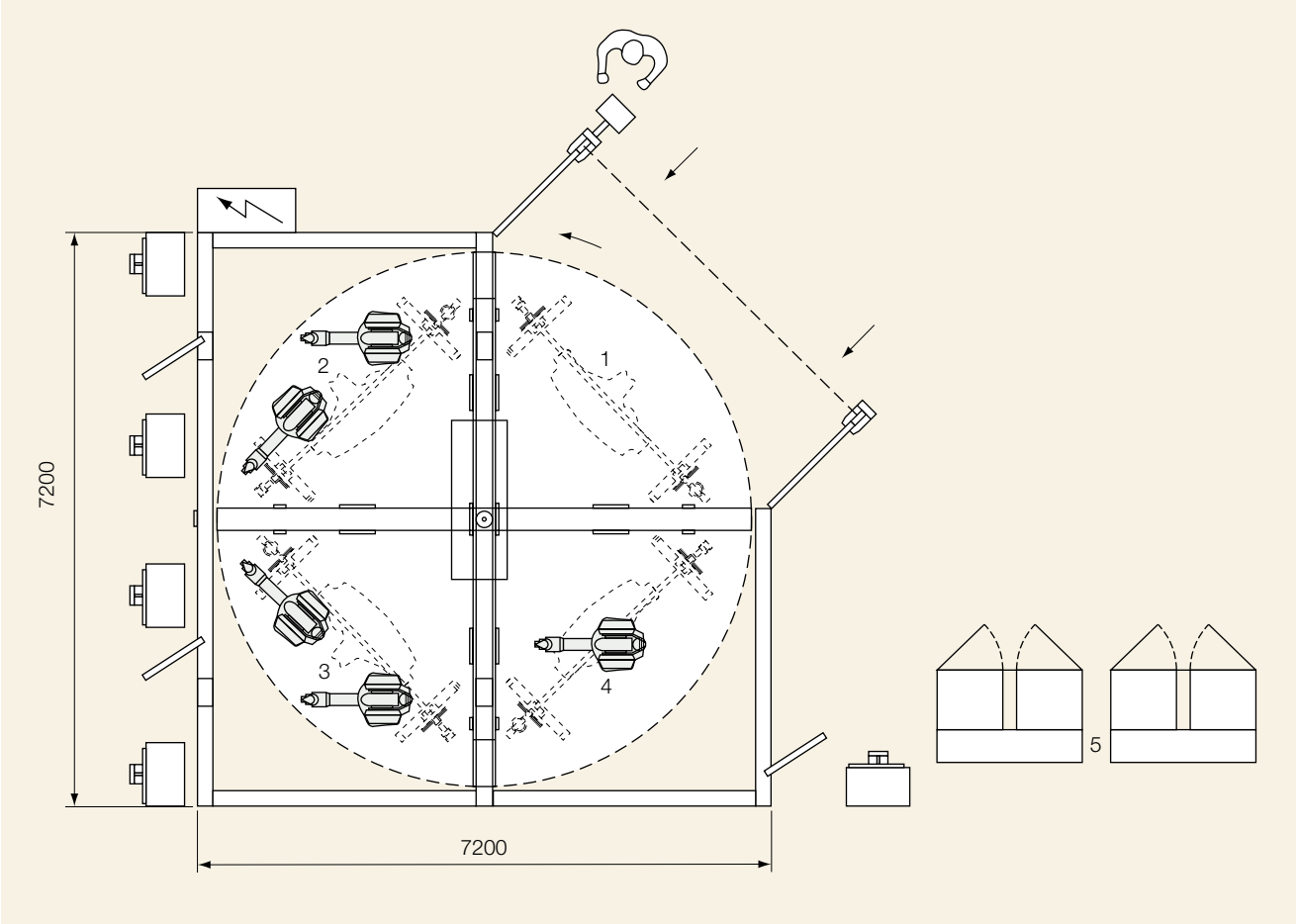
Different cutting boxes are available

ABB I-R offers a range of cutting boxes that meet all requirements. The design of the boxes underscores the diversity of the applications for which waterjet cutting is suitable. *Cutting Box Small Part* is the name given to the 'lean' concept with just one robot for the manufacture of smaller-size components 8. The inclined rotary worktable allows optimum utilization of the space available in the box, while a large degree of freedom in the choice of site is offered by the module's ease of transport and installation. As a rule, it can be installed and commissioned within three days. This cutting box is designed as a stand-alone system.

ABB offers the *Cutting Box Original* as a production center for larger workpieces. This box also represents the basic concept around which each waterjet cutting system is built 9, 10. One or two robots can be installed, if required with a track motion system and a standardized pallet system. Other options, such as shell-lifters and handling robots, turn this box into a universal production plant which can usually be installed and taken into operation within just a week.

The outstanding feature of the *Cutting Box Fourwing* is a four-station rotary table on which workpieces can be processed one after the other in several operations 11. One or two robots can work at each station. A variety of finishing operations, such as cleaning or milling, can be integrated.

'Cutting Box Original', equipped with two type IRB 2400 robots and an automatic shell-lifter, used to cut car headliners 10



'Cutting Box Fourwing' with a four-station rotary table for processing workpieces one after the other in several operations. Deburring and cleaning are among the finishing operations that can be incorporated in this box. **11**

1 *Loading position*
2 *Fixture in cutting position 1*
3 *Fixture in cutting position 2*
4 *Milling*
5 *Streamline high-pressure pumps*

Cutting carpets for passenger cars

The *Cutting Box Productive* is integrated in the production line. Designed for manufacturing carpets for passenger cars, the system is equipped with four cutting robots of type IRB 2400 in two stations, plus handling robots of type IRB 6400 S for the fully automatic manipulation of the carpets and top shell-halves. This cutting box is designed to produce 900 parts per shift for a cycle time of 30 s. A wide range of carpets can be manufactured with it.

The concept for large-scale production with short cycle times has been realized in the *Cutting Box Fourrob*. In this box, four robots of type IRB 2400 can work simultaneously on one workpiece. The concept, which is geared to high production speeds, combines short cycle times with high flexibility.

A considerable growth rate is expected

The prospects for waterjet cutting are excellent. A high growth rate is anticipated for the future on account of the economy and environmental soundness of the technology. Experience with systems already installed underscores the reliability of the method as well as its technological and cost advantages over traditional methods such as punching and laser or plasma cutting.

References

[1] B. Assarsson: Robotized waterjet cutting. ABB Review 6/7-93, 3–10.

[2] Å. Madesäter: Faster and more accurate industrial robots with the new S4 controller. ABB Review 2/95, 31–34.

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