3D – Waterjet Cutting
with Endlessly Rotating Cutting Head

The waterjet cutting systems HYDRO-JET from KNUTH which are well proven 2D systems in various industrial sectors, can now be optionally equipped with a 5-axis cutting head. The feature of endless rotation offers substantial advantages for the processing of cutting jobs. This cutting head also allows higher component accuracies for the 2D - Cutting with, at the same time, increased cutting speeds due to the compensation of the downwardly tapered cutting kerf by an adapted angular setting.

Compared to both the plasma jet cutting and laser cutting, waterjet cutting has greatly gained in importance in recent years, so it is an industrially accepted cutting technology today. It does not require electrical conductivity of the material and does not dependent on a sufficient absorption of the laser beam. Therefore, it can be universally used for a variety of materials. By adding an abrasive to the high-pressure waterjet, a very effective material removal is achieved within the narrow cutting kerf in the case of massive materials.

In contrast to the thermal cutting methods, there is no critical overheating of the cut material by the "cold" waterjet cutting, even at very slow feed. Therefore, it can be used also for large work-piece thicknesses up to more than 100 mm. This circumstance makes it especially interesting that on flatbed - waterjet cutting systems not only cut surfaces can be produced which are perpendicular to the sheet surface, but also beveled cut surfaces which are inclined by any angle required. For this the cutting head does not only need the three Cartesian coordinate axes (X and Y for generating the cut contour and Z for positioning the cutting nozzle to the work-piece surface), but additionally it must have two axes of rotation making possible that the waterjet can be set under any required angle to the surface at any location in the working area of the cutting machine.

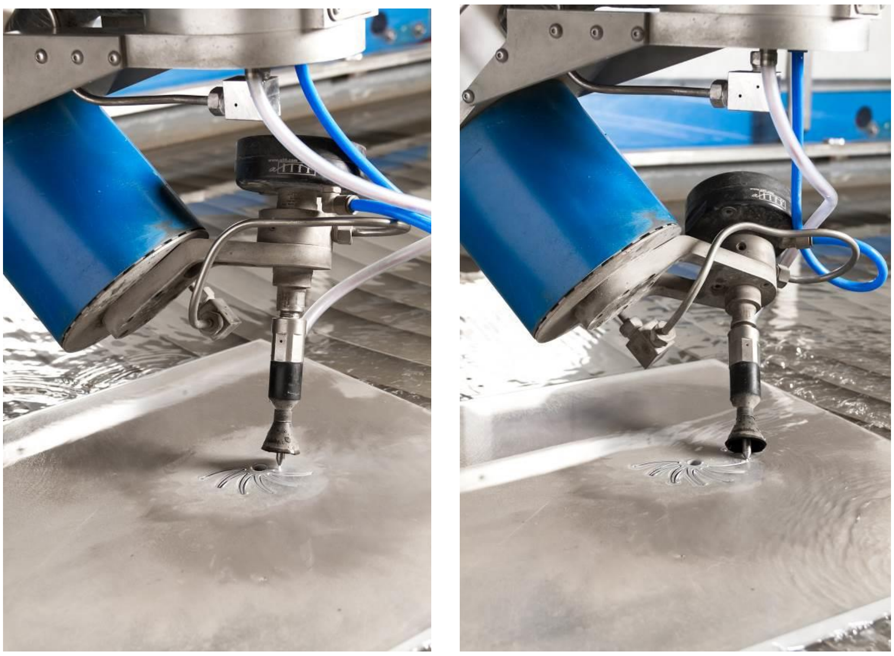


Figure 1
Spatial movement of the 5-axis cutting head newly developed during waterjet cutting of an impeller
(Photos: KNUTH Machine Tools)

The 5-axis cutting head developed by KNUTH is based on the design principle of the Nutator, wherein the two axes of rotation are at an angle of 45^0 to each other: On the one hand, a rotation around the Z-axis and, on the other hand, a rotation around an axis orientated under 45^0 to the Z-axis which forms a 45 nutation cone when the cutting head rotates around the Z axis. The tip of this nutation cone is chosen as the "Tool Center Point". In the case of waterjet cutting, this is the center of incident of the waterjet on the work-piece surface. Rotational movements of the cutting head thus lead to no change of incident position. This has the advantage that for a change of the waterjet direction no compensatory movements of the linear axes X, Y, Z must be made. The modern 5-axis cutting heads from different manufacturers are designed predominantly according to this principle.

The rotation around the Z-axis yields the limitation that it cannot run endlessly without further measures, because the supplies for electrical energy, electronic signals, compressed air, high-pressure water, and the abrasive must be transferred into the cutting head and these cannot be wound up multiple times. In particular, the feeding hose for the abrasive must be vacuum-compatible and free of setting edges in order to guarantee a uniform dosage of the abrasive. Because of this limitation the machine control has to be implemented with a numerical tool ensuring foresight that during the operation on the cutting contour all the necessary rotational movements can be performed without having to re-rotate the cutting head in between. Indeed, there are cutting head assemblies in which rotation around the Z axis is not necessary due to a special lever mechanism which generates the inclinations of the cutting head. However, this principle frequently used in plasma cutting systems has the disadvantage that it cannot hold the counterforces of the emitted waterjet as well as the nutator arrangement with its high rigidity. For waterjet cutting, this mechanical stability is most important in order to achieve a high accuracy of the cut parts.

Figure 2
Waterjet cutting system HYDRO-JET Eco 1525 equipped with the newly developed 5-axis cutting head
(Photo: KNUTH Machine Tools)

To overcome the limitations of the rotation around the Z-axis, at the 5-axis cutting head developed by KNUTH, suitable rotary feed-through were selected for all supplies. For electricity, compressed air, and high-pressure water existing feed-through solutions have been chosen. However, a special rotary element had to be designed for the abrasive that allows a continuous transport of the abrasive sand under the various conditions of processing and for the different sand properties. This has been solved successfully, so that now **the waterjet cutting systems from KNUTH can be equipped with an endlessly rotating cutting head for 3D cutting** as an option.

The advantages of this 5-axis cutting system are

- that restoring movements of the cutting head are avoided and thus the non-productive times of the machine operation are reduced,
- that rapid changes in angle can be performed by the cutting head which otherwise would not be permitted due to the compensating movements of the other axes and due to their available acceleration capacity,
- and, in particular, that **contours can be created without interruption of the cutting process, which require rotations around the Z axis with a multiple of 360^0** (e.g. cutting of spiral contours).

The maximum angle of inclination is $\pm$ 51^0. Additionally, the cutting head has been designed so that components subject to wear are used only in a minimal number. Only one rotary element is installed in the high-pressure water supply, while the other movements are enabled by tube deformation. The overall structure is designed so that **the necessary service work can be executed comfortably** and needs to be done only at long intervals.

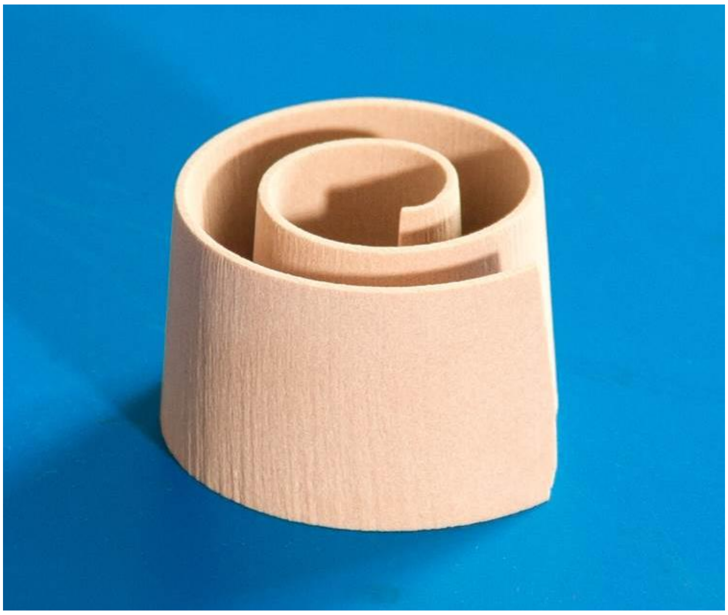
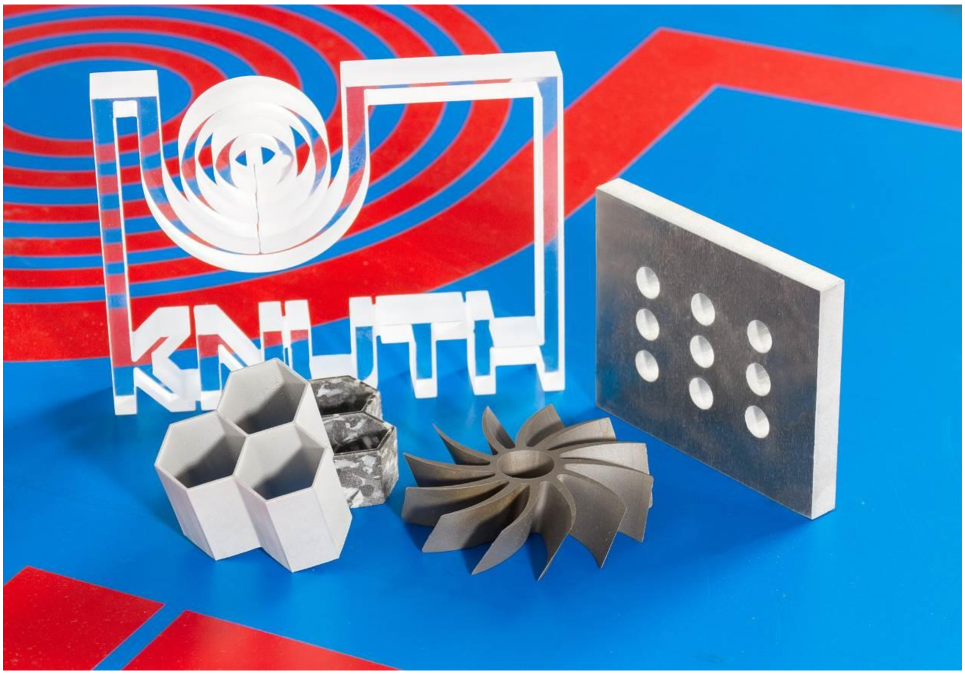


Figure 3
3D waterjet cutting produced spiral of a mineral hard-material, wherein the spiral walls have a trapezoidal cross-section (element height 25 mm, base diameter 42 mm, wall thickness above 1.5 mm and below 4.0 mm)
(Photo: KNUTH Machine Tools)

The 5-axis cutting head offers major advantages for the 2D cutting as well: The erosion process in the cutting kerf is characterized by the fact that the kerf width becomes smaller downwards. This effect is the more pronounced the higher the cutting speed is selected, and in the most extreme case, is of the magnitude of half the kerf width at the waterjet entrance. Therefore, the requirement of a high accuracy of the cut part requires the setting of reduced cutting speeds in the case of a pure 2D cutting machine. At the same time, this also improves the cut surface quality significantly. By help of the 5-axis cutting head, however, the inclination of the resulting cut surface can be directly compensated by a corresponding angular setting of the cutting head. The angle to be adjusted is depending on the momentary cutting speed, on the type of material and on the plate thickness. It is calculated by a special software automatically (taper compensation). **The efficiency of a waterjet cutting system thus can be significantly increased especially in the case of high accuracy requirements.**

Figure 4
By help of the 5-axis cutting head produced specimens of various materials satisfying the following requirements: Acrylic glass (20 mm thick) with cut the surfaces being absolute perpendicular, Aluminum sheet (10 mm thick) with perpendicular cut surfaces and precisely formed holes (10 mm diameter), Impeller of steel with smooth blade surfaces which have a defined curvature, Honeycomb-shaped structures with a constant wall thickness, cut from a 40 mm thick aluminum plate (remaining wall thickness of 1 mm) as well as from 20 mm thick artificial stone (remaining wall thickness 2.5 mm)
(Photo: KNUTH Machine Tools)



The deviations of the cut surface from the target level can be observed well below 0.1 mm, and this not only at the upper plate surface (entry side of the high-pressure waterjet), but all over the cut surface. With good alignment of the motion axes and with not yet worn cutting nozzle and focusing tube, high-quality holes with smooth inner surfaces can be produced having diameters at the top and bottom side which differ only by 0.01 mm for up to 40 mm thick material.

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Author: Dr. Ingo Decker
Technology consultant at KNUTH Machine Tools