Full Range of Waterjet Cutting Machines with Optimum Cutting Quality in 2D and 3D

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For over 10 years, the waterjet cutting systems of KNUTH Machine Tools have proven worthwhile in industrial use. Manifold customer experiences have been incorporated into the development, and the machine portfolio is constantly expanding. Today, in addition to the standard Hydro-Jet series, Premium Line cutting machines with automatic cut angle control for highest accuracy and quality standards are available as well as machines with a 5-axis cutting head for 3D processing. The machine working areas are ranging from 1.5mx0.5m especially for fine cutting jobs up to large systems with a 4mx3m wide cutting area.

Compared with plasma or laser cutting as the thermal cutting methods, waterjet cutting is a "cold" cutting process which, even at very low cutting speeds, does not generate a critical overheating of the material being cut. Therefore, the waterjet can be applied to large work piece thicknesses of more than 100 mm. It is the most universal cutting technology, since it neither requires an electrical conductivity of the material, nor it depends on a sufficient absorption of a laser beam. By the addition of an abrasive to the high-pressure waterjet, a very effective material removal is achieved in a narrow (1mm or less wide) kerf for weak or hard materials as well.

Figure 1

Cutting with high-pressure waterjet
(Photo: KNUTH Machine Tools)

The **quality of the cut surface** produced depends strongly on the set cutting parameters and on the characteristics of the cutting system used. As shown in the picture, both an extremely smooth cut surface without any cutting grooves and bounded by exact cut edges can be produced as well as fast rough cuts with pronounced grooves increasing downwards along the surface resulting in a wavy-lined

bottom cut edge. In between the two cut qualities shown there are 5 selectable levels of quality and a difference in the cutting speed by a factor of 6.6:

- Cut surfaces of the highest quality result in the case of slow feed, since the high-pressure waterjet cuts not only at the forward front of the cutting kerf, but also "grinds" on both sides the emerging cut surfaces by the abrasive grains transported in the waterjet. Prerequisite is an absolutely uniform cutting operation: no noticeable pressure surges in the waterjet caused by the high-pressure pump, no blockages of the abrasive supply, and no interference of the jet flow by wear or poor quality of the water nozzle and of the collimation tube.
- At high cutting speeds, however, the kinetic energy of the abrasive grains accelerated within the high-pressure waterjet is no longer sufficient to abrade the kerf material. Only the onset of a tailback of material in the kerf provides the necessary impetus for the expulsion, i.e., the cutting process converts to a pulsating mode which is manifested in the formation of cutting grooves.

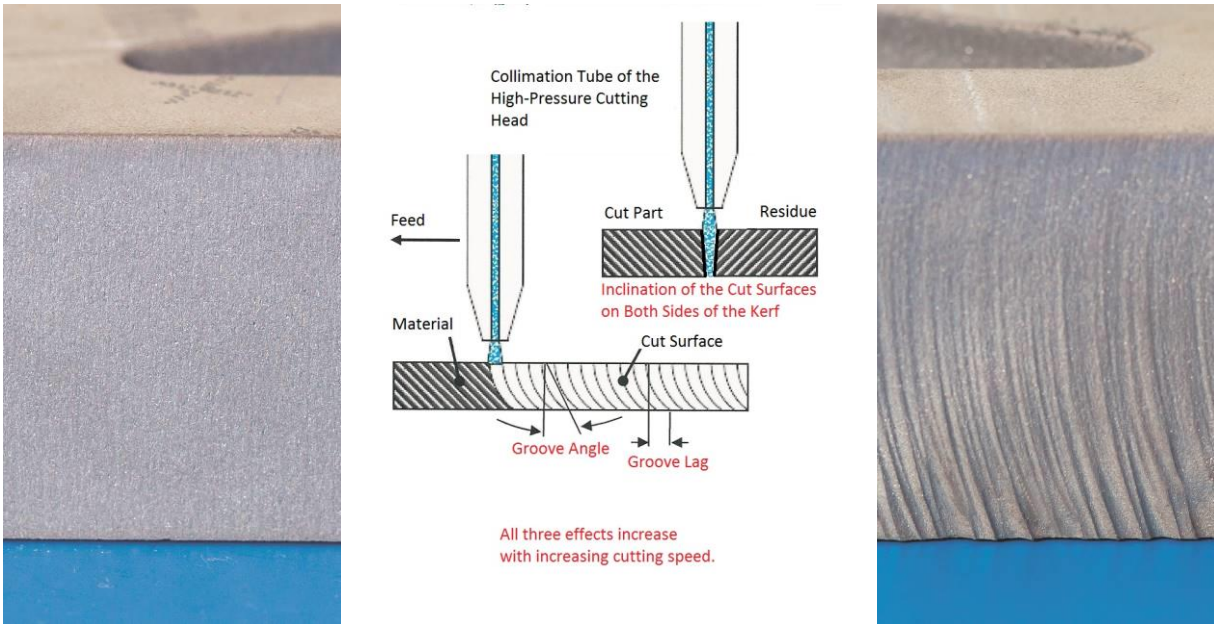

Figure 2 Cutting surfaces on 25mm thick plates of stainless steel
Left: Highest cut quality produced with slow feed
Right: Fast rough cut at 6.6-fold higher cutting speed
Middle: Groove formation and cut surface inclination as quality characteristics
(Photos: KNUTH Machine Tools)

A second aspect of the cut quality is the **dimensional accuracy of the cut parts**. As indicated in the picture, the erosion process always results in a kerf, the width of which decreases downwards so that a small inclination of the cut surface to the waterjet direction is inevitable. Accordingly, the cut parts are always slightly larger on the bottom side than on the top. This effect is the more pronounced the higher the feed is selected and reaches the order of one third of the kerf top width at the maximum cutting speed possible for the material thickness in question. The maximum inclination with respect to the exact vertical cut surface is 0.6 degree in angle in case of a 40mm thick material.

This means that, even in the case of a fast rough cutting, the dimensional deviations of the cut parts remain smaller than 0.8mm.

This dependence implies for the case of a pure 2D cutting system, e.g. for the economical machines of the Hydro-Jet series of KNUTH, that for the manufacturing of post-processing-free cut parts of high accuracy the feed must be controlled down as far as the required dimensional accuracy is achieved. This has to be done even if the smoothness requirements of the cut surfaces would allow higher cutting speeds. Since the cutting time increases by the same factor as the feed is reduced and since the cutting costs per time unit remain the same, such accuracy requirements increase the part production costs accordingly.

Figure 3

Cutting Machine Water-Jet 3015 of series STAHLWERK Premium Line with a cutting area 3mx1.5m. The abrasive-mud extraction system is located behind the machine.
(Photo: KNUTH Machine Tools)

An alternative solution is provided by the **higher-quality cutting machines of the series Water-Jet in the STAHLWERK Premium Line**. These machines have a cutting head with a 2-axis low-angle tilting device integrated. This allows both the automatic compensation of the cut surface inclination - taper angle control - (resulting in an inclination of the opposite cut surface at the material residue twice as large) on the one side as well as a forward tilting of the cutting head on the other side, such that the lag of the grooves is minimized thus enabling the cutting of parts with small radii and corners at higher feed: Depending on the momentary cutting direction and feed rate, depending on the type of material and material thickness, and depending on the other cutting parameters such as water pressure, nozzle diameter and abrasive supply, the angular orientation of the cutting head is continually adjusted by a special software. The dimensional deviations between the upper and the lower side of the cut parts can thus be kept smaller than 0.03mm for material thicknesses up to 40mm. The tracking sensitivity for the cutting-head angle is of the order of 0.025 degree, i.e., it is one twenty-fourth of the above mentioned maximum inclination angle of the cut surfaces which can occur in pure 2D waterjet cutting, thus yielding a sufficiently accurate angle control.

Such precise tilt compensation enables extremely high accuracies of the cut parts if also the movement of the cutting head along the X- and Y-axis is of correspondingly high precision. The achievable cut quality is clearly shown by means of the KNUTH logo-piece: The pattern consists of two cut parts which are arranged during the cutting

as indicated in the picture on the left side. The insert piece in which the arcuate segments are cut in a 90-degree-rotated orientation relative to the frame piece, can be pressed into the frame part backlash-free and without gaps occurring along the arches. This is possible both in the same material layer as well as in the inverted position of the insert piece with the back plate side up.

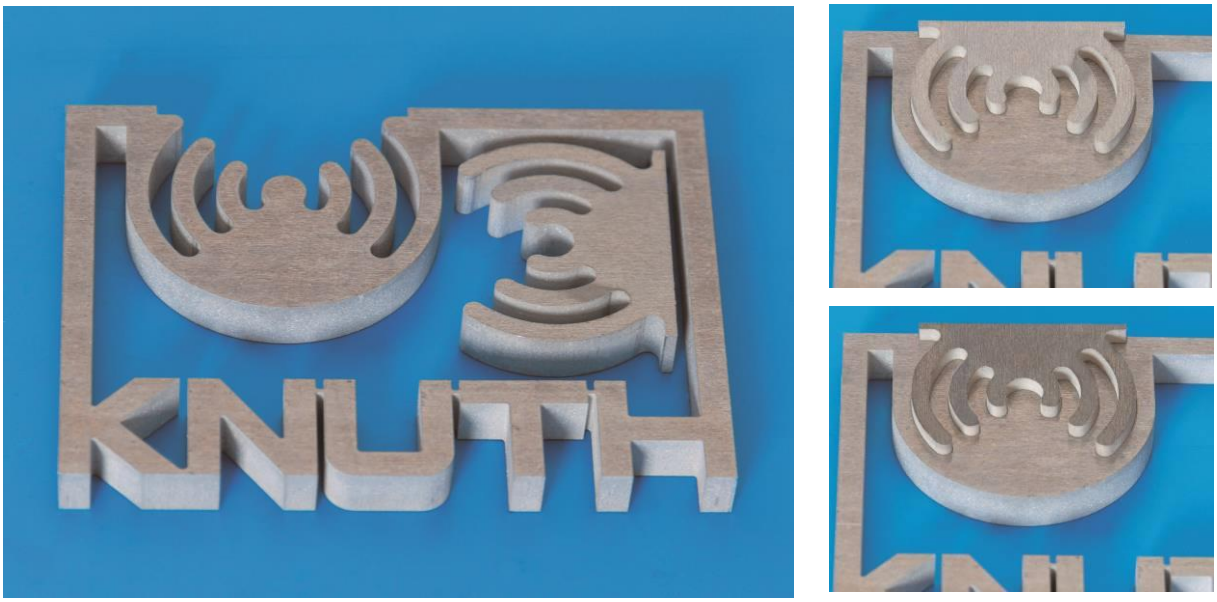

Figure 4 Waterjet-produced cut pattern (two pieces) made from 10mm thick aluminum sheet. The back plate side has been stained before (appears darker).
Top right: Insert part pressed into the frame in the same material layering
Bottom right: Insert part pressed-in with the back plate side upwards
(Photos: KNUTH Machine Tools)

For bevel cutting, machines are available with a 3D cutting head of 5 axis of movement. The **3D cutting head developed by KNUTH** is based on the design principle of nutation: Moving the cutting head in the two rotational axes does not change the position of the tool center point where the waterjet impinges on the work piece. Hence, no compensational movements in the linear axes X, Y, Z are to be made for a change in the angle of the waterjet direction.

Figure 5

Water-Jet cutting machine with an endlessly rotatable 3D cutting head
(Photo: KNUTH Machine Tools)

The **special feature of this 3D cutting head** is that it **can be rotated endlessly** around the Z-axis. This enables to perform without any interruption cutting contours which require cutting head rotations around the Z axis of a multiple of 360 degree (e.g., cutting spiral contours). For the same reason, the 3D cutting head can advantageously be used for the taper angle control of cut surfaces and for the minimization of the groove lag by forward tilting. This makes the 3D cutting head extremely economical since, on the other hand, additionally to the usual bevel cutting, it can be used to cut complex 3D parts. It is capable of full 3D processing after enabling the machine control to simultaneously interpolate all 5 axes of motion.

Figure 6

With 3D waterjet cutting produced impellers out of 18mm thick steel (top), 22mm thick acrylic glass (bottom left) and 8mm thick aluminum (bottom right)
(Photo: KNUTH Machine Tools)

The mechanical design of the waterjet cutting machines of KNUTH in all cases is adapted to the different levels of required quality and aims at the best possible manner of handling: For all machines, the water basin is mechanically decoupled from the machine frame so that the machine movements are not affected by the energy input to the water basin caused by waterjet cutting. The high-precision Premium Water-Jet machines are built with machine bridges that span the long axis of the cutting area (easier loading of the plates and removing of the cut parts on both long sides) and that are moved by a precision gantry drive. In contrast, the Hydro-Jet series operates on the flying bridge concept, which provides an ideal accessibility of the cutting area on 3 sides.

Finally, great attention is given to the reliable operation of the machines installed at the customer´s site. All machines are equipped with reliable BHDT high-pressure pumps, for which as well as for all the components of the high-pressure water system an extensive stock of all spare and wear parts is set up. If required, a quick service ensures that there is no long machine downtime and that quick assistance is given to the customer for implementing his new cutting tasks.

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