

# **Water Jet Cutting**

## **A Technology on the Rise**



## **Water Jet Cutting- A Technology on the Rise**

### **Foreword:**

The purpose of this brochure is to give the reader a rough overview of Waterjet Cutting. In addition to precise cutting of various materials as presented, many special applications i.e. medical and in the decommissioning and demolition field exist – these however being outside the scope of this text. For any additional information, our KMT Waterjet team is always available. Also, we would like to welcome you to visit our homepage [www.kmt-waterjet.com](http://www.kmt-waterjet.com), where you have the option of downloading useful files.

In order for you to get a better understanding of KMT Waterjet Systems, we would also like to take this opportunity to present our company.

In the Autumn of 2003, KMT AB of Sweden purchased the Waterjet Cutting Division from Ingersoll-Rand. The KMT Corporation is an Internationally active corporation with over 700 employees worldwide. KMT Waterjet Systems employs 200 people. Further KMT brands include UVA, LIDKOPING, KMT Robotic Solutions, KMT Aqua-Dyne, KMT McCartney, and KMT H2O. The focus of all of these brands is metal working in Industrial Applications.

The KMT Waterjet production facility in Baxter Springs, Kansas USA has been manufacturing High Pressure components and pumps for over 50 years. The majority of these is used in Waterjet Cutting, however notably the Petrochemical Industry has also been a large customer of our pumps for over 50 years.

Over 150 top quality specialists work in this area, developing, manufacturing and designing these high-tech units for over 50 years. KMT has over 6500 waterjet cutting pumps in worldwide service. Our European Headquarters in Bad Nauheim, Germany, services the European market, plus Africa, west Asia and China. This is where we take care of customers from

Siberia to Iceland, from Norway to South Africa.

Specially trained technicians are constantly on duty and can help you immediately at any time.

Service and wear parts are shipped within 24 hours.

Our contract-cutting department takes care of our customers' needs to the fullest, enabling us to perform test-cutting procedures in order to optimize the cutting method, allowing you for economically and technically sound operation of your machines.

The KMT Waterjet team in Bad Nauheim is always available to answer your questions!



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## 1. Introduction

Since ages, nature has proven that even the hardest materials change their form and shape when water is applied to them.

The structures created by this phenomenon can be both useful and beautiful.

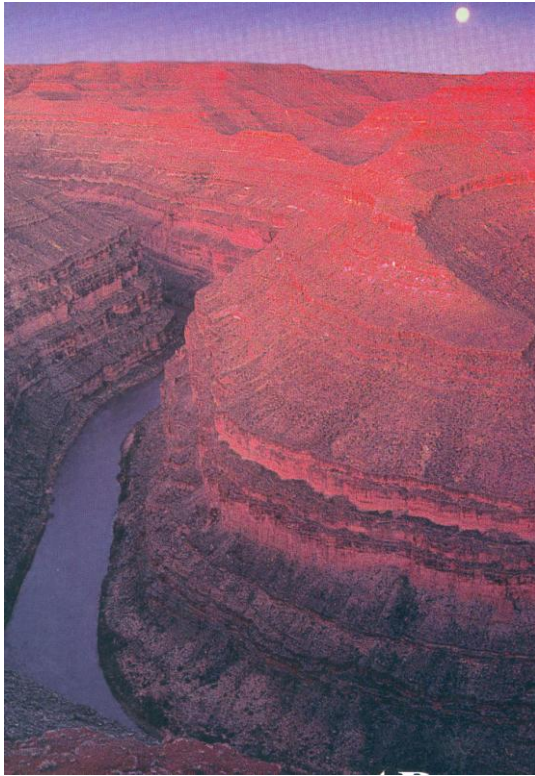


Fig. 1 The Grand Canyon was cut by water flowing through stone.

In the process of mineral erosion of stones, it is not only the flow of water that plays an important role. Also, the implications of air and mineral particles i.e. sand, moving with the water, play an important role.

Almost the whole surface of our planet is and has been influenced by such processes in one way or another.

## 2. History

The German folk saying has stated for ages that a steady drop of water can drill a hole in a stone. The real life applications of pressurized water date back to the 19<sup>th</sup> century, when Californian gold miners of the 1870's used it to remove layers of sand and rock. The 1920's mark the beginning of the use of water jets for the removal of stones and sand in daily construction work. These jets had characteristically large flow rates with pressure levels reaching a few hundred bar; which is the combination necessary to move the large volumes of material, as required for mining applications. Precise cutting in the modern understanding of the word, was not possible at the time.

In the 1950's, McCartney Manufacturing of Baxter Springs, Kansas, USA, developed the first Ultra High Pressure Pumps for Catalyst injection in Low Density Polyethylene production. In 1963, McCartney was acquired by Ingersoll-Rand. McCartney was sold to KMT Waterjet in the Autumn of 2003.

In 1968, Dr. Norman Franz, a Professor at the University of British Columbia, Canada, patented a concept of a Waterjet Cutting machine with a cutting pressure of 700 bar.

The first commercial application came into life already in 1971. A system devised by the KMT Waterjet subsidiary McCartney Manufacturing was used for cutting of paper tubes and was an instant success.

At that time, only pure water cutting was used. The cut materials included paper diapers as well as honeycomb materials used in the aerospace industry, which were difficult to process using traditional methods.

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Fig. 2 Without waterjets, diapers would have been much more difficult to produce...

Since the early 1970's, Ingersoll-Rand has been manufacturing pumps generating a continuous output pressure of 3.800 bar. Another Ingersoll-Rand subsidiary, Best Matic, developed a machine in Europe for cutting wooden puzzles.

Pure water is very well suited for cutting of soft, hard, and sensitive materials in a very precise manner. Unfortunately it is not possible to cut very hard materials such as ceramic tiles, steel, glass, or stone.

To overcome this shortcoming, tests were conducted with adding hard abrasive particles to the jet. In the early 1980's this technology left the laboratory. In 1984, Ingersoll-Rand's hydroabrasive division was created.

The development of capable Robotic arms opened a completely new large application area of „Cutting Boxes“ mainly for the manufacturing of 3D automotive parts e.g. headliners, or consoles.

Today, KMT Waterjet does not build any complete waterjet cutting systems. Instead, our focus has been on the continuous development and improvement of our top quality high pressure components, as well as the very strong support of our system partners active in the Machine Tool, Stone, Glass, and Food businesses as well as many other areas of material processing.

### 3. Operating Principles

Every cutting method is based on the input of energy into the material, in order to overcome the chemical bindings present in the structure of the material. Thermal cutting methods, for example, utilize the energy of chemical reactions, electricity, or light to produce high temperatures in order to melt the material at the cutting kerf.

Mechanical methods utilize the kinetic energy of the moving tool or form ductile materials through the application of pressure.

Waterjet Cutting can be classified as a mechanical method. The energy of the rapidly moving jet is utilized either in the form of a pure waterjet or abrasive waterjet and then applied to the workpiece causing microerosion. The cutting water works as a cooling agent of cutting edge, thus allowing for a very high quality cut.

The one main component which is without any doubt always necessary to create a waterjet is the high pressure pump.

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Fig. 3 Streamline PRO-I High Pressure Pump from KMT Waterjet Systems

Direct drive pumps offer large volumes of high-pressure water. Their pressure ranges, however, are limited, especially at the top end. Their main area of application is in the areas, where large cutting power without very good accuracy is required, i.e. in the construction industry, surface cleaning, material removal, etc.

For cutting applications, so-called Intensifier pumps are mainly used. Their pressure of the primary (oil) circuit is achieved through the use of a variable displacement pump, only to be multiplied by 20 in the reciprocating intensifier topworks.

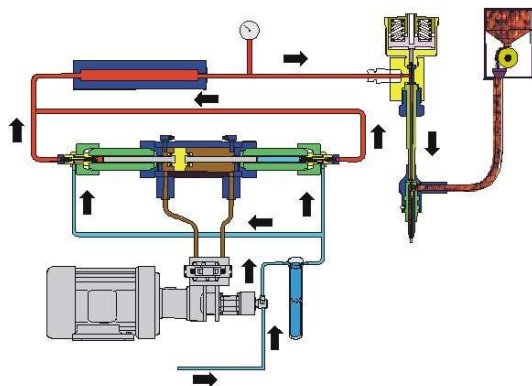


Fig. 4 The Intensifier principle: An electric motor drives a hydraulic pump (below) pressurizing the oil circuit of the intensifier (center), where the pressure is increased 20 times and fed into the system (above)

These pumps have power ratings between 10 und 149 KW (15-200HP) generating

output pressures of over 6.200 bar and flow rates between 1,5 and 15,2 l/min.

The water is transported through special high pressure tubing, which is partially flexible, allowing for the movements of the cutting head. The head consists of a pneumatically controlled needle valve and a nozzle tube, at the end of which a special conus fitting a jewel orifice (most commonly diamond or sapphire) is mounted with a special nut. It is in this very nozzle that velocities of Mach 2-3 are achieved.

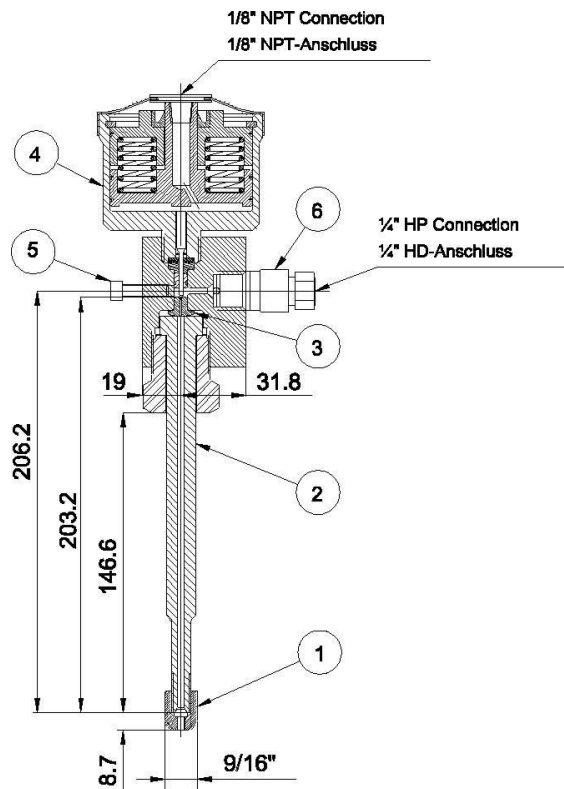


Fig. 5 KMT Waterjet Pure water cutting head

For abrasive applications, a special Abrasive head is used for mixing the sand with the high pressure water beneath the water orifice.

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Fig. 6 KMT Waterjet Autoline Abrasive Cutting Head

The movement of the cutting head is usually controlled by a CNC controller of the cutting table.

The material is placed on a grid above the water tank, which serves the purpose of disbursing and capturing the energy of the jet upon exiting the workpiece.

In most cases, conventional tap water can be used as the cutting medium. In some cases however, a conventional water softener is applied. Extremely pure, distilled water should not be used, as without any dissolved ions, the water tends to react with the high-pressure components, causing excessive wear.

For abrasive applications, the bulk transfer system and the sand feeder are part of the machine as well as possibly a sand removal and recycling unit in some rare cases.

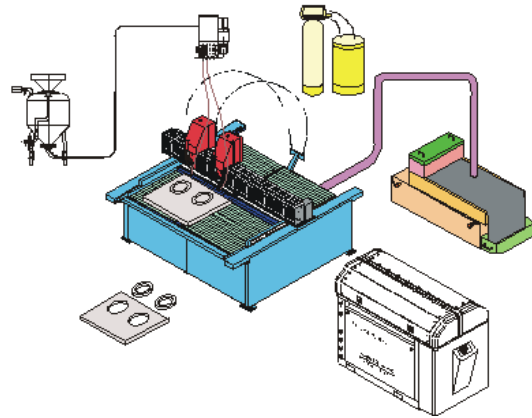


Fig. 7 A cutting machine with water preparation, STREAMLINE SL-V High Pressure Pump, Waste Filtration, and ABRALINE sand feeder system

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### **4. Advantages of Waterjet Cutting:**

#### **Pure-water**

- Flexible production
- Environmentally friendly
- Small kerf
- Better material utilization
- Cutting in all axes
- High speeds for various materials
- Easily adaptable to automatic contouring
- Easy programming with standard CAD/CAM systems
- Fits multiple-axis systems
- Easily integrated into flexible production systems
- Just-in-Time production
- Quick prototyping
- Only simple fixtures required
- Small tangential forces on cut material
- No heat affected zones
- Stress free cutting
- No material jump-off
- No tool sharpening
- No dust, fumes, or gases released

#### **Hydroabrasiv <sup>TM</sup>**

- Flexible production
- Small kerf
- In most cases eliminates after-cut machining
- Better Material Utilization
- Cutting in all axes
- High speeds for various materials
- Easily adaptable to automatic contouring
- Easy programming with standard CAD/CAM systems
- Fits Multiple-axis systems
- Easily integrated into flexible production systems
- Just-in-Time production
- Quick prototyping
- Only simple fixtures required
- Small tangential forces on cut material
- No heat affected zones
- No uncontrolled thermal tempering or hardening
- Stress free cutting
- No metallurgical deformation
- No material jump-off
- No tool sharpening
- No dust, fumes, or gases released



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### 5. Two types of cutting

Let us take a closer look at the basics of the two waterjet cutting methods.

#### Pure-water cutting

Pure waterjet is used mainly for relatively soft materials such as plastic, textiles, paper, sealing materials, metallic foils, plywood...

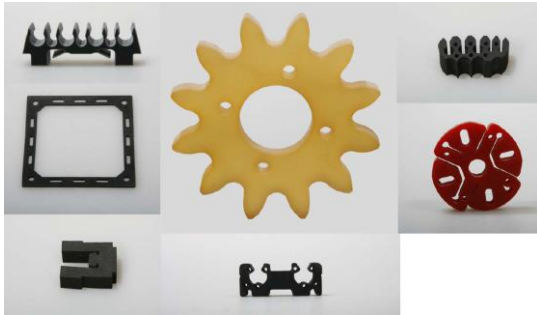


Fig. 8 Pure water samples cut at KMT Waterjet, Bad Nauheim

These materials can be cut at very high speeds. The limiting factor is usually not the cutting power of the cutting head, but the ability of the movement device to move quick enough.

When trying to cut a material at 20m/min, it is not very likely that the cutting head will have a chance to accelerate to this high speed within a small workpiece.

Examples:

Paper and plastic foils up to 200 m/min  
Carpeting: 15 - 30 m/min.

For such materials, waterjet is used for cutting of production runs, where it is used as an alternatives to blade cutting.

A pure waterjet has the width of a hair at around 0,1 mm- 0,2 mm and is therefore able to cut very sharp contours. Parts requiring positive-negative inlays, can be put together without any problem whatsoever. A company logo embedded in a floormat is highly desirable from a customer's standpoint.



Fig. 9 Plastic Inlay Floormat for a Club

Another interesting application field is in the area of seal manufacturing. A press is much quicker; the tooling costs however are so high, that only high production volumes are feasible. Waterjet, on the other hand, allows for production in small runs, i.e. 100 cylinder head seals, for a rare automobile.

In combination with an optical recognition system and a nesting software package a waterjet cutting machine is able utilize a piece of leather in an optimal way.



Fig. 10 Leather cutting machine with optical recognition system and nesting

The raw leather is placed on a table, and scanned by a digital camera, in order to find defects (i.e. holes, discolorations, etc.), which are recognized by the camera. The special software is able to optimize the material utilization based on the different shoe sizes.



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The water used for cutting has to be at least the purity of drinkable water, therefore, waterjet is very well suited for applications in the food industry.

Frozen fish, previously available only in sticks, now can be cut into sea horses, stars, whatever shapes found desirable and attractive, especially to kids...

When cutting cake, it is certain that a forgotten cherry seed does not stick to the blade leaving an ugly looking mark. Chocolate also can be cut with nice edge quality.

At the end of a pure water cutting head, a nut holds a cutting orifice encased in steel. When the nozzle is worn, it can be replaced within minutes.

### Hydroabrasive-cutting

The hydroabrasive application is used for harder materials:

Metals, Glass, Stone, Concrete, Glass composites, Ceramics and hard materials like Aluminum oxide or Silicone Oxide.



Fig. 11 Metal, Stone and plastic materials cut at KMT Waterjet Bad Nauheim

The hydroabrasive method is somewhat more complex. In addition to the supply of high pressure water, a sand feeding system is necessary. Instead of the nut, an abrasive cutting head is required – this is where the mixing of the water and sand occurs.

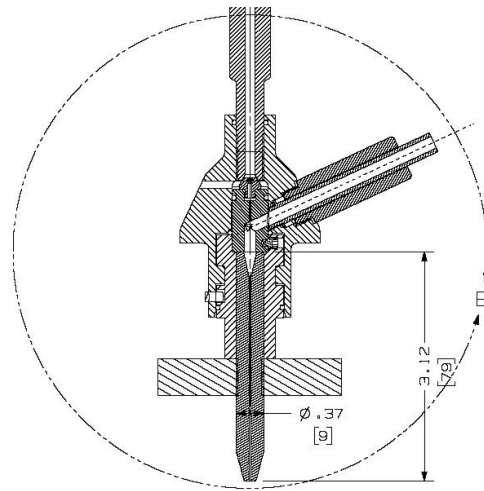


Fig. 12  
View of the KMT Waterjet AUTOLINE Abrasive cutting head

After the high pressure water passes through the water orifice, it flows into the mixing chamber. Because of the high velocity, the jet causes a vacuum, thus sucking in the mixture of air and sand through the entry port. The sand quantity is controlled by the abrasive feeder.

In order to bring this mixture into alignment, a focusing tube with a conically shaped inlet of three times the diameter of the water orifice is required. Even small geometrical variances have an impact on the cutting parameters.

In most cases, Garnet sand and Olivine are used as abrasive. Both are natural minerals, which are mined and can be purchased at relatively reasonable prices (0,25 to 0,50 €/kg). One abrasive cutting head requires 250 –600 g Abrasive per Minute.

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Fig. 13 Small parts cut at KMT Waterjet Bad Nauheim

The typically used grades are between 50 –120 Mesh (Mesh per inch as known from sandpaper) comparable with fine beachsand.

The used Abrasive can be recycled to a certain extent or can be used in construction applications.

Abrasive cutting is substantially slower than pure water cutting. The speeds are in the hundreds of mm/min and in many cases even less, depending of course on the material, thickness, and required surface quality. However, one must not forget that very hard materials and large thicknesses can be cut.

One of the main areas of cutting are metals between 5 and 20 mm, which cannot be efficiently cut with other methods i.e. Stainless Steel, Copper, Brass, Titanium.

These materials can be cut without heating the cutting edge, without stress and with a clean cut that seldom required post-cut finishing work.

As far as the upper thickness limits, there is no real limit. Around 90% of the applications are between 3 and 30 mm, then perhaps 9% up to 100 mm. The

remainder are special cases, outside of this range – 180 mm concrete plates, 400 mm Steel parts.



Fig. 14 180mm thick concrete plates cut at KMT Waterjet, Bad Nauheim

All of this is doable, the costs and the processing time in these cases rises significantly, and in the end, it is really an economical question.

The Kerf width of 1mm is dramatically thinner than most milling tools, allowing for cutting of even finer contours. In addition, it is possible to start directly inside the material, without pre-drilling of entry holes.



Fig. 15 10 mm Stainless Steel Sample

The diversity of possible shapes and forms is astounding.

Abrasive cutting is not however limited to the metal working area. In the stone industry, waterjet cutting is used in the production of inlays. Decorators are

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discovering the wide possibilities offered by the ability to produce exact holes; stone kitchen countertops can be cut to exact specifications and dimensions.



Fig. 16 The Labrador flower was inserted in a Marble tile at KMT Waterjet

When cutting glass, two small tricks are introduced:

When possible, olivine sand is utilized.



Fig. 17 20mm Glass Double Eagle

Olivine is not as hard as garnet, thus cutting somewhat slower. However, at the same time the part is cut, the upper surface of the glass is polished. The second key element of glass cutting is the use of lower pressures in the piercing process, in order to prevent the breakage of the usually brittle material.

As you see, we have covered a wide variety of materials.

As of today, we know no material which waterjet cannot cut through. (March 2010).

### 6. 1D-2D-3D

In addition to the division of applications into Pure Water and Abrasive, the applications can be broken down by the geometrical shape.

#### One Dimensional:

In production applications, slitting and continuous waterjet cutting is often used. The frame of the system is usually quite simple, cutting speeds are quite high.

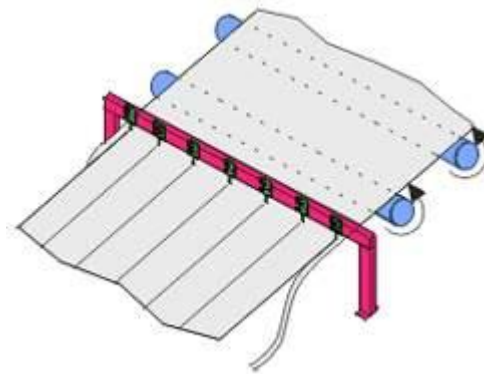


Fig. 18 Slitter for cutting of plastic foil

The very important criterion in this application is the high reliability and short stand still times of waterjet cutting over long cutting periods.

In contrast to roll cutting, the material is not moved to the side and no airborne dust is created.

Many cutting heads can be applied and controlled at the same time.

Application areas: Paper and Plastic production, Gypsum boards, Raw drywall plates, sheet metal, Cake, Frozen pizza, etc...

#### Two Dimensional:

The most popular application is the 2D cutting table. The cutting head is located above the cutting tank, moves in X-Y axes, according to the outputs given by the CNC-Controller. In many cases the Z (height) axis is controllable, in order to adapt to non-flat surfaces. The controller is more complex and most of the cutting speeds lie below 15 m/min.



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Fig. 19 Four-Head Cutting table at KMT Waterjet in Bad Nauheim]

As opposed to milling, the jet creates no tangential forces on the work piece, so the material does not need to be mounted to the machine in very sophisticated ways. Only light materials must be held down in some manner in order to prevent fly-away caused by water spurting water. This allows for quick material change.

Typical table sizes include 1x2 m, 2x3 m und 3x4 m, mainly with 2 - 93 KW.

Bigger machines are also produced.

### Three Dimensional:

There are two subgroups of 3D applications: Robotic applications, where the cutting head is mounted on a robotic arm and cutting tables, where, in addition to the 3 X, Y, and Z axes, a rotation and swivel axis are added.

Robotic applications are able to cut automotive soft materials such as headliners, dashboards, door panels, cutting out shapes not accessible to presses.



Fig. 20 Robot with KMT Waterjet Cutting head for automotive customer

A cutting head with 5-Axes can perform conical cuts of flat material sheets and cut chamfers as well as perpendicularly situated holes in tubes. In engineering applications, the bottom end of titanium tubes used in chemical reactors can be cut without weakening the material.



Fig. 21 5-Axis- 3-D Cutting machine with KMT Waterjet Cutting Head]

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### 7. Cutting Parameters

One of the most frequently asked questions in Waterjet Cutting is:

- Which materials can be cut?
- What are the cutting speeds?
- What is the maximum thickness?

Generally, numerous "soft" materials can be cut with waterjet. Our understanding of "soft" is quite a wide one indeed. Leather, paper, foams, or carpets are certainly soft. Harder rubber, plywood up to 10mm, fiberglass up to 6mm, but also thin sheet metals or foils can be cut with pure water.

The abrasive waterjet has almost no limitations – there is no difference between cheap construction steel or stainless for this method – both are cut equally well. Stone, thick plywood, glass, metals and plastics can be processed in this manner. Also the hardest materials such as Aluminum Oxide, Silicone Nitride, and Silicone Carbide can be cut. The jet is not sensitive to chemical resistance of the material, and is not concerned whether the material is optically reflective or not, electrically conductive or not.

Our technicians came across one material which was very difficult to waterjet – Wolfram Carbide – this is why the earlier focusing tubes were made of this hard metal. But this material can also be cut, it is just a matter of cutting speed.

### 8. Cutting Speed

The speed depend on many factors:

#### 1. Material thickness:

The speed is related to thickness in a non-linear manner – basically for half the thickness, the speed is more than two times greater.

#### 2. Diameter:

A thicker nozzle carries more energy thus increasing the cutting speed. A nozzle of twice the diameter carries four times the volume of high pressure water; the speed increase however is only 80%. Therefore it often is practical to use smaller nozzles with multiple heads running in parallel.

#### 3. Abrasive Feeding:

The speed can be also increased by increasing the Abrasive feed rate. Here again, a doubling of the feed rate does not result in a doubled cutting speed – depending on the thickness the result is an increase of 20-40%.

#### 4. Pressure:

A higher cutting pressure brings more energy into the workpiece, thus increasing the cutting power. At higher pressures, the abrasive feed rates can be increased without blocking the focusing tube. Both effects lead to the conclusion that by a pressure increase of 10%, more than 10% cutting speed can be achieved.

#### 5. Cut quality:

Depending on whether a contour is to be simply cut out of the material, or the piece should be in the top quality possible, the unit cost can go up by even five times.

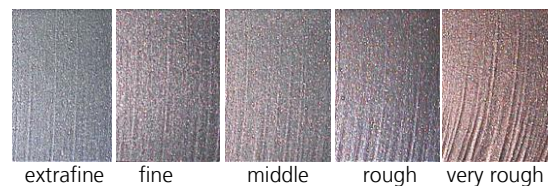


Fig. 22 A extra fine cut may take five times as long as a very rough one

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A very quickly guided waterjet, which just manages to cut through the material, has a V-shaped profile, creating a uneven surface at the bottom.

Should the jet be guided in a slower fashion, the profile will be more even. As a general rule – at one fifth of the maximum cutting speed, a perfectly perpendicular with a near perfectly polished surface is achieved.

A further slowing of the movement speed, leads to a loss of guidance in the material, erosion in the lower sections of the work piece, and a creation of an A-shaped profile.

### 9. The idiosyncracies of Waterjet

Keeping in mind the wide spectrum of possible applications – there are a few areas, which are somewhat challenging for this cutting method.

The jet does not like large openings in hard materials. When cutting a multi-layer profile at the top of the workpiece, a slowdown in the velocity of the outside of the jet is observed, while at the same time, the center of the jet maintains the high kinetic energy. As a result, upon exiting the first layer of the material, an increase in width of the jet occurs – resulting in inferior cutting quality and parameters

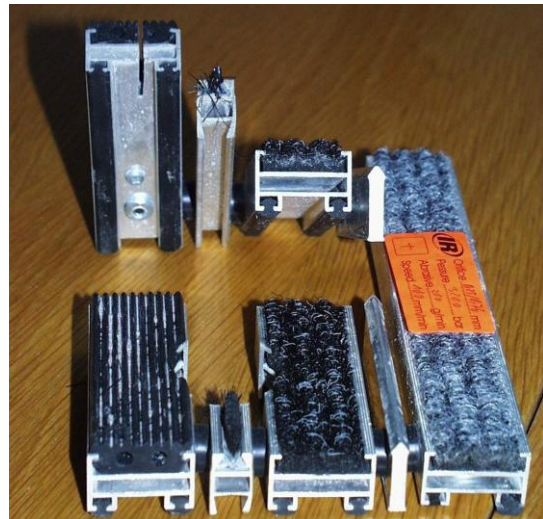


Fig. 23 Aluminum profiles cut with Waterjet

When cutting piles of sheet metal, it is important to make sure the plates are as flat as possible in order to prevent the creation of pockets between the layers. By tube cutting, the jet on the lower side of the tube is somewhat wider.

A solution here can be a rotating system facilitating the rotation of the tube in the process of cutting.

Keeping these considerations in mind, waterjet is very well suited to cut multi-layer materials.



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Fig. 26 Cable with isolation, Plastic with metal inserts Velour/Foam/Fiberglass material

Plastic coated iron, plastic foil covered aluminum, styrofoam covered gypsum board ...

Waterjet technology was used for the removal of the Russian "Kursk" nuclear submarine from the bottom of the sea. The steel body was covered with a thick layer of rubber. And this gets us to yet another advantage of this method – it is not affected by moisture, working also under water.

### 10. Costs

What is the cost of waterjet cutting?

A generalistic answer to this question is not possible – in general you get what you pay for – and this applies here as well.

Depending on the application – be it a CNC controlled cutting table or a Robotic cutting box – the required investment is quite different.

It is important to know if the discussion is about a small pump with one head or a large pump or pumps with multiple heads running in parallel.

Regional electricity, water and abrasive sand prices change these costs significantly.

Taking the costs local to the Rhein-Main area of Germany – we arrive upon rough figures of:

Per PW head: 5-8 €/h

Per Abrasive head: 16-20 €/h

In addition, wages, interest costs, and administration, depending on each individual company set up must be calculated. In order to help you with the daily computations of these costs based on practical numbers, KMT Waterjet developed a special software package, allowing the user to quickly and easily compute the costs based on the speed, material and cutting length.

KMT Waterjet based in Bad Nauheim, Germany is always available to help you. Please contact us anytime, especially with specific applications questions.

## **Water Jet Cutting- A Technology on the Rise**

### **11. Additional information:**

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