Feature

Cutting robots: a review of technologies and applications

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Abstract
Purpose – The purpose of this paper is to provide a review of robotic cutting techniques and applications.
Design/methodology/approach – This paper firstly describes the main cutting techniques used with robots and subsequently discusses robotic cutting applications, giving examples of specific uses.
Findings – This paper shows that robotic laser, water-jet, ultrasonic, plasma and oxy-gas cutting techniques are used in a wide range of industries on materials which include plastics, metals, fabrics, foodstuffs and even human tissues. The use of a particular technique reflects application-specific factors such as material, thickness, precision, cut quality and cutting speed.
Originality/value – Provides an introduction to robotic cutting techniques and their applications.

Keywords Robotics, Material-removal processes, Automotive industry

Paper type Technical paper

Introduction

Material handling and welding applications dominate the industrial robot market in value terms and cutting and material removal represent only around 5 per cent of the total. Nevertheless, cutting robots are being applied to a growing number of applications in many industries and involve materials ranging from metals and stone to fabrics, plastics, foodstuffs and human tissues.

Robotic cutting uses similar techniques to those employed in non-robotic processes, i.e. water-jet, laser, ultrasonic, plasma, oxy-gas and knives and blades. The use of a particular method reflects application-specific factors such as material, thickness, precision, cut quality and speed. The cutting mechanism is usually located on the robot arm and the part is presented to the cutter by a conveyor, turntable or manipulator, although an option is for the robot to hold the part and move it relative to a fixed cutting tool.

Cutting techniques

Water-jet

Water-jet cutting uses a stream of water from a pump or accumulator, pressurised to around 45,000-60,000 psi ($\sim$3,000-4,100 Bar) which generally contains an abrasive such as garnet when cutting metals or other hard materials. Figure 1 shows a water-jet cutting robot and the key benefits and limitation of this technique are summarised in Table I.

Laser cutting

Laser cutting is a thermal process whereby a focused laser beam is used to melt material in a localised area. A coaxial jet of "assist gas" is often used to eject the molten material from the cut to leave a clean edge. A typical robotic laser cutting system consists of a servo-controlled, multi-axis mechanical arm that has a laser cutting head mounted to the robot's faceplate. Laser power has increased progressively and units offering powers from a few hundred Watts up to 3 kW or more are now available. The main types of laser are CO_2 and Nd:YAG; the former delivering the light via mirrors whilst the latter generally employ optical fibres. Some systems employ an oxygen flow along the beam path which increases cutting speed by fuelling exothermic reactions.

Maintaining the correct beam focus at the work-piece can be problematic and whilst this is simple to control when the parts are flat metal sheets it is far more difficult when cutting 3D, stamped sheet metal. Such applications require the active control of the focal position which can be achieved with capacitive sensors which provide feedback signals to adjust the position of the robot arm and maintain it at the optimum height. In high power, high-cutting speed applications, high-speed auto-focus end effectors are used which allow the vertical adjustment of the beam-delivery unit, independent of the robot arm, thus overcoming the issue of inertia.

The main benefits and limitation of laser cutting are summarised in Table II and Figure 2 shows a laser cutting robot.

Ultrasonic cutting

This relies on a conventional type of metal blade or cutting tool being excited with ultrasonic energy from a piezoelectric transducer via a sonotrode (Figure 3).

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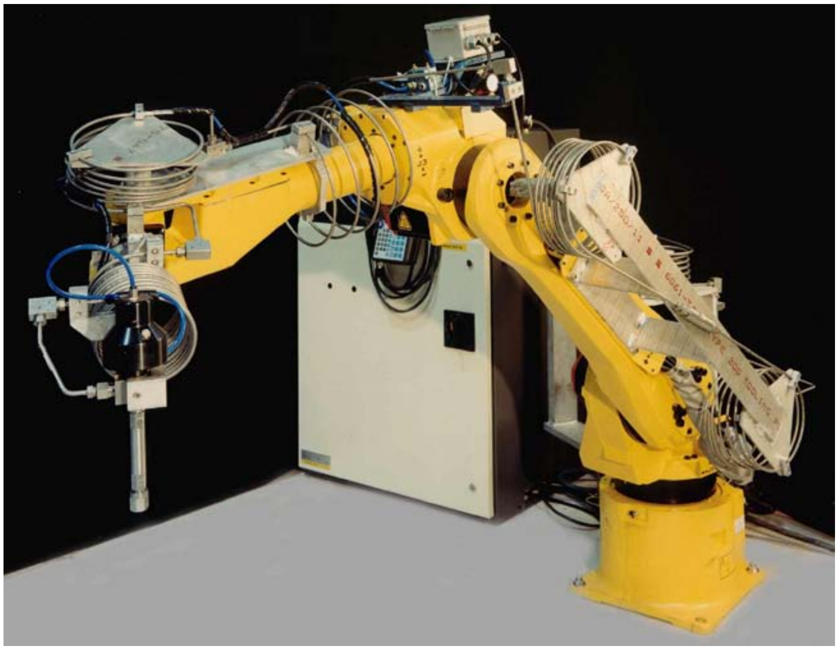
Figure 1 A water-jet cutting robot



Source: Robotic Production Technology

Table I Benefits and limitations of water-jet cutting

Benefits	Limitations
Can be used on many different materials (metals, plastics, fabrics, stone, rubber, composites, etc.)	With hard materials the cutting rate has to be greatly reduced, leading to often very long cutting times
No heat generated (important with materials where heat may change their properties)	Very thick parts cannot be cut and still retain their dimensional accuracy
Does not produce any dust or particles that may be harmful if inhaled	Difficult to use on fibrous materials
The kerf width is very small and little material is wasted	
Does not leave a burr or a rough edge, eliminating the need for subsequent finishing operations	
Jet heads are light, which eases the problem of accelerating and decelerating the robot head	

Table II Benefits and limitations of laser cutting

Benefits	Limitations
Can be used on many materials	Cannot be used with transparent materials
Produces high-precision cuts, particularly on thin gauge materials	Some materials (e.g. plastics) create toxic fumes during cutting
Narrow kerf widths	Complexity of laser control systems
Often higher cutting speed than water-jet	
Does not leave a burr or rough edge	
Small heat affected zone (for a thermal technique)	

Figure 2 Robot equipped with a laser cutter

This causes the tool to vibrate unidirectionally, typically at a frequency of 20-40 kHz, with an amplitude of 10-20 μm, transforming the cutting process into a series of micro-impacts. The lower frequencies are suitable for thicker, harder materials, whereas higher frequencies are best for foil and thin films. Ultrasound reduces greatly the force required on the tool, allowing the cutting of hard materials such as Kevlar or ceramics, as well as very soft

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Figure 3 Sonotrode and tips used in ultrasonic cutting

products such as foodstuffs. The benefits and limitation of ultrasonic cutting are summarised in Table III.

Plasma cutting

In this process, a gas such as nitrogen, oxygen, argon or air is blown at high speed out of a nozzle; at the same time an electrical arc is formed through the gas from the nozzle to the surface being cut, turning some of the gas into plasma. The plasma has a temperature of approximately 30,000°F (16,649°C) and a velocity of around 20,000 ft/s (~6,000 m/s) and is sufficiently hot to melt the metal being cut and sufficiently fast to blow molten metal away from the cut. The plasma conducts electrical current and the cycle of creating the arc is continuous as long as power is supplied to the electrode and the plasma stays in contact with the metal. In order to ensure this contact, protect the cut from oxidation and regulate the plasma, the cutter nozzle has a second set of channels which release a constant flow of shielding gas around the cutting area.

When used on a robot, this technique necessitates the use of a smoke removal hood, a screen to keep dirt off of the robot and electrical isolation components to prevent high-frequency currents from affecting the robot's electronics. The benefits and limitation of plasma cutting are summarised in Table IV.

Table III Benefits and limitations of ultrasonic cutting

Benefits	Limitations
Good for hard, soft and brittle materials	Cannot cut thick metal samples
Minimal heat-affected zone	Cut features are governed by tool geometry
High accuracy, narrow kerf	Tool wear
High quality finish	
No dust or fumes	

Table IV Benefits and limitations of plasma cutting

Benefits	Limitations
Good cutting speed, faster than oxy-gas	Restricted to electrically conductive materials
Clean cut with little or no dross	Gas consumption
Produces a small and more precise kerf width than oxy-gas	Need for electrical shielding
Smaller heat-affected zone than oxy-gas	Need for smoke removal hood
Can cut aluminium and stainless steel (impossible with oxy-gas)	

Oxy-gas cutting

This is the best known thermal cutting technique, whereby a torch produces a high-temperature flame from the combustion of oxygen and most often acetylene which is used to heat the metal to a temperature of about 980°C. The flame is not intended to melt the metal but to bring it to its ignition temperature. A stream of pure oxygen is then trained on the hot metal which chemically combines with the iron and then flows out of the cut as iron oxide slag. The benefits and limitations of oxy-gas cutting are listed in Table V.

Table V Benefits and limitations of oxy-gas cutting

Benefits	Limitations
Simple, well established technique	Cannot cut aluminium or stainless steel
No electrical shielding required	Slower cut rate than plasma
	Produces a larger kerf than plasma
	High gas consumption
	Larger heat-affected zone than plasma

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Applications

Water-jet cutting robots

The automotive industry is the dominant user of robotic water-jet cutting. This technique has been used widely since the 1990s, where water-jet cutting robots have frequently replaced trim dies as a means of creating cut-outs in soft parts such as foam components, insulating and sound dampening materials, carpets, headliners (Figure 4) and other fabrics and plastics. On straight cuts, an abrasive water-jet can cut at speeds from 800 to 1,500 mm/s, depending on the material. Glass mats, made of reinforced polyurethane foam, are cut more slowly, at around 40 mm/s, whilst hard plastic skins are cut at 300 mm/second. Automotive carpets and headliners, which generally range in thickness from 4.75 to 6.5 mm, are typically cut at speeds of 1,500 mm/s.

Robotic water-jet cutters are also used by the food industry, for example to cut fish fillets. Systems frequently use lasers or other imaging systems to scan and characterise the product on a moving conveyor and then cut it to a pre-programmed weight and shape.

At the other extreme, water-jet cutting robots can be used on very hard materials, an example being natural stone such as granite or marble. A system developed by Finnish company Stone Automation comprises a six-axis Kura KR 210 robot fitted with a high-speed saw blade and a water-jet and is used to cut out shaped stone countertops. The saw is used to cut all the long, straight seams and the re-entrant corners, arcs, circles and ellipses are cut by the water-jet. Other hard material applications of water-jet robots include cutting titanium parts such as fan blades and other jet engine components and cutting and weld preparation of large metal tubes.

Laser cutting robots

As with water-jet, many laser cutting robot applications are in the automotive industry and most involve plastics such as PP, PE and ABS. Examples include cutting plastic parts for vehicle interiors such as dashboards and boot mouldings, exterior covers and trim and under-bonnet components. Other uses include cutting and trimming sheet metal stampings and complex deep-drawn parts for vehicle bodies and the pre-weakening of airbag covers.

The Robocut product family, produced by Robot Technology GmbH, is an example of a dedicated 3D laser-cutting robot. Combining a Rofin-Sinar 300 W laser with an ABB IRB 4400 robot creates a system capable of cutting nearly all plastics as well as thin sheet metal. The integration of the laser tube and the RF-power supply into the robot arm eliminates excess cabling with just power and cooling water connections required at the robot. An integral diode pointer simplifies the beam alignment process, whilst also removing some of the guess-work out of cutting path programming. Assist gas is internally fed to the head so as to reduce the axis-movement limitation, which can be a drawback on externally fed systems. Axes 4 and 5 of the Robocut are endlessly rotating so that reversed rotation of these after cutting does not increase cycle times. The beam path consists of four adjustable mirrors delivering the laser beam to a 3.75-in. focal length lens. The robot offers a maximum tool centre point (TCP) speed of 2.2 m/s and a TCP acceleration of up to 1.4 g. The working radius is 2,536 mm. Repeatability is ± 0.035 mm, with a path accuracy of ± 0.2 mm at a contouring speed of 1 m/s. While this is about half the accuracy achieved by a five-axis CNC system, the Robocut price is between 30 and 45 per cent of the cost of a CNC. Two systems have recently been installed by German plastic component manufacturer Montaplast who produces parts for automotive exteriors, interiors and engine compartments for companies such as Volkswagen, DaimlerChrysler, Audi and Opel (Figure 5). These systems are being used to cut a range of components with cutting speeds of up to 7,000 mm/s with 0.01 mm repeatability and allow the plant to process up to 1,200 components each day.

Figure 4 Gantry robot water-jet cutting an automotive head lining

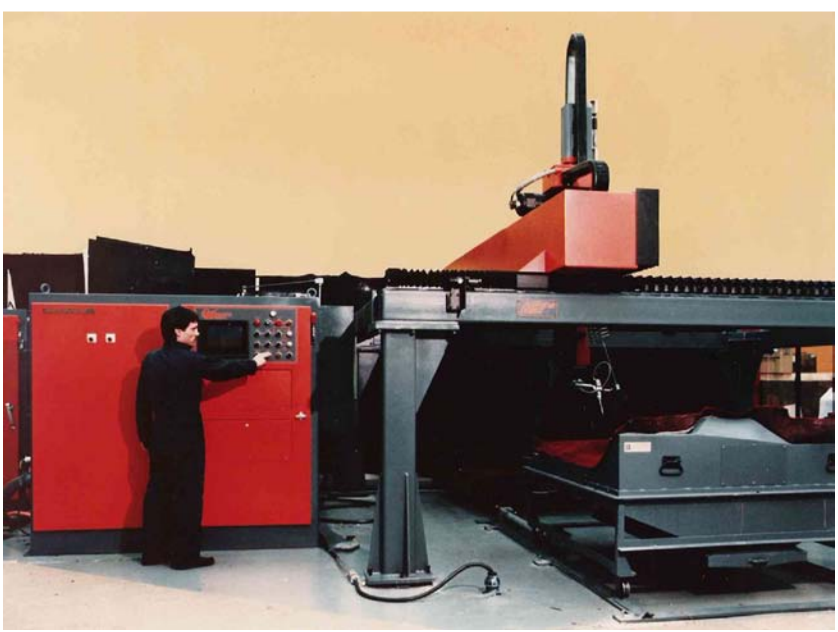

Figure 5 Automotive component supplier Montaplast is using laser cutting robots to improve efficiency and cutting quality on a range of plastic parts

Ultrasonic cutting robots

Although used widely in non-robotic applications, e.g. in automated systems to cut carbon fibre, etc. ultrasonic cutting finds fewer robotic uses than either laser or water-jet. There is limited use by the automotive component industry, for example, for trimming plastic parts such as instrument and door panels. Nevertheless, there is a growing interest in this technology and in 2007, KMT Robotic Solutions, Inc. announced the launch of RoboKnife RT-200, a dedicated, six-axis ultrasonic cutting robot, developed with Branson Ultrasonics Corp., which is aimed at cutting soft materials such as rubber, foam, fabrics, textiles, plastics and vinyl. The 3 ft wide, 9.5 ft deep system features a riser-mounted FANUC M-6iB/6S robot and a servo-controlled rotating fixture table that enable it to trim parts up to 24 in. long, 24 in. wide and 30 in. high (Figure 6).

An important and growing use is in the medical sector, where so-called "ultrasonic shears" can be used with surgical robots, the best known being the da Vinci system produced by Intuitive Surgical, Inc. (Figure 7). Introduced in 2001, the shears are a result of a collaboration between Intuitive Surgical and Olympus Optical Company Ltd The shear blades vibrate at 55 kHz and cut through tissues and, most importantly, simultaneously seal the blood vessels within them, significantly reducing blood loss. These devices allow the surgeon to seal vessels up to 7 mm in diameter without having to tie or clip them. Research at various universities is presently underway with the aim of developing surgical ultrasonic osteotomy (bone cutting) tools.

A further soft material application is in the food industry, where robotic ultrasonic cutting has been used to a limited degree for cheese slicing.

Plasma cutting robots

Plasma cutting robots are being used increasingly for a range of often heavy-duty, mostly steel cutting operations (Figure 8). Some examples include:

- cutting steel pressure vessel parts;
- cutting girders for steel fabricators;

Figure 6 RoboKnife RT-200, a dedicated ultrasonic cutting robot

Source: KMT Robotic Solutions, Inc

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Figure 7 The da Vinci robotic surgery system can cut tissues with ultrasonic shears

Source: © 2008, Intuitive Surgical, Inc.

Figure 8 Motoman robot, plasma cutting a steel plate

- cutting steel rods and tubes for use in supermarket trolleys;
- cutting and weld prep on pipe-work in shipyards, including nuclear-powered aircraft carriers and submarines;
- cutting steel carriers for use in high-speed shuttle machines; and
- cutting parts for high-pressure compressors.

The robots have often replaced manual cutting processes which were frequently highly labour-intensive and conducted with oxy-gas torches. In the case of fabricating pipe-work for nuclear-powered vessels at Newport News Shipbuilding, Inc., several oxy-acetylene-based manual cutting stages were involved which were both slow and prone to high-reject levels, even where simple joints were involved. The process has been replaced by five-axis, plasma cutting robots which greatly reduced cutting and weld prep time, as well as improving quality, and yielded an estimated annual savings of $30 million per year per robot. In other instances, high-capacity robots have been used because of the size and weight of the components involved. During shuttle machine construction, ABB IRB 7600 six-axis robots, which have a capacity of up to 500 kg and a reach 2.5-3.5 m, move and cut the steel carriers for the foundation of the machines that weigh up to 55 tons. The robot brings the 2.5 m long steel carriers, weighing 200 kg, to the positioning station, cuts the holes at the correct positions with the plasma torch and then treats the cut edge with a wire brush so that the steel sheets can be tacked onto them. It then mounts the carrier into a rotating welding station and independently takes small sheets from the magazine and positions them at the programmed location. A smaller IRB 2400 welding robot then tacks them on. After all sheets have been attached, it welds them while the IRB 7600 prepares the next carrier.

Oxy-gas cutting robots

Few cutting robots use this technique, although some can use either oxy-gas or plasma. A benefit of oxy-gas is its ability to cut greater material thickness than can plasma, although the cutting speed is generally lower. As with plasma, cutting

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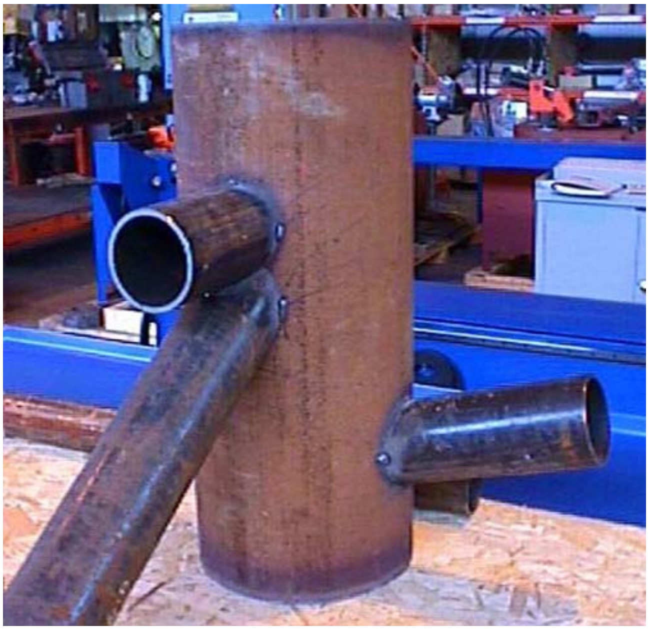
complex section of pipe-work is a common application and an example of a system aimed at this use is based on a Fanuc, eight-axis robot, developed by US-based Jesse Engineering. This is used mostly in shipyards to cut complex pipe sections, prior to welding (Figure 9).

Figure 9 Complex sections of pipe-work, cut with an oxy-gas cutting robot prior to welding



Robotic cutting with blades and knives

Robotic cutting and slicing is also conducted with conventional knives and blades, particularly in the food industry. An emerging application is in the meat processing sector, where robots are increasing being used to cut pork sides. An example is a Kuka six-axis KR 125 robot equipped with a two-camera vision system and a circular blade cutter which is being used by a Norwegian company, Hedmark og Oppland Slakterier BA, to cut pork sides, each weighing between 70 and 120 kg. The system can cut over 400 sides/h. Another system, installed at Mitchell's Gourmet Foods' Saskatoon plant is based around a Fanuc M-710i robot equipped with knives and a vision system. A servo feeder first synchronises pork bellies on a main cutting conveyor. These then pass through a data acquisition station where a camera analyses the topology and uses a laser beam to triangulate sections. The image is used to determine all the cutting parameters which are then transmitted to the robot; the entire process taking just 2.5 s. The robot is equipped with eight double-sided Denver knives and is able to change knives automatically. Designed to work in a slaughterhouse environment, the robot arm is protected by a pressurised wash-down sanitary cover so it can withstand cold temperatures, high-ambient humidity and high-pressure cleansing at up to 600 psi. The system can process 700 hogs or 1,400 bellies per hour, the same volume previously achieved by a six-person crew.

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