PLASMA CUTTING UNDERWATER
SAFE WORKING WITH HIGH VOLTAGE

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WHY CUT METAL UNDERWATER

There are many reasons why we might wish to cut metal below water; to remove damaged or corroded parts for repair or replacement, for salvage operations, decommissioning of redundant structures or modifications to structures, whilst they effectively remain in service. In each case the ability to cut metal in the wet environment obviates the need for dry-docking or the construction of a dry habitat, with considerable savings in time and cost. The important factors are diver safety, speed of cut, and the process cost. In the case of repair or modification, quality of cut is significant.

EXISTING METHODS

Most established methods of cutting metal underwater can be divided into two categories, mechanical and thermal. Most mechanical methods in use are abrasive, using rotating discs, generally with hydraulic power, or reciprocating diamond abrasive “saws”. These methods are generally slow and restricted to straight line cuts but these are of good quality. The process cost is generally high.

There are many different thermal methods in use, but the majority use oxygen to effect the cutting process.

There are a number of variations on the Oxy-fuel process, such as is widely used on the surface, using gaseous or liquid fuels. There are a number of arc processes, most using oxygen and a consumable electrode, although some use an electrode with a gas producing flux to eject molten metal from the arc region.

These methods generally offer moderate speeds and high process costs. There are safety concerns in the use of oxygen, as small explosions have been known to result and cause injury or death to divers.

These arc processes are known to cause electric shock to divers, but these are not considered life threatening and appear to be tolerated.

The quality of cut of these processes is, however, not generally very good, and will often require further work, certainly if welding repair is required. This usually involves abrasive processes and their associated low speed and additional high process cost.

THE PLASMA PROCESS

The plasma cutting process has been around for more than 40 years. Initially an inert gas process intended for cutting stainless steels and non-ferrous materials. it has become a process widely used for all metals, and most commonly using compressed air as the process gas. It works by causing an electric arc to be constricted by a nozzle. This forces the arc energy into a smaller beam, and at the same time changes the arc characteristic, particularly by increasing the voltage, to allow high energy levels to be input into this small beam. The result is very high temperatures and rapid melting/vaporisation of the work-piece, in other words high cutting speed.

The process cost comprises electric power, and consumable parts within the cutting torch, principally the electrode and nozzle. Particularly because of the high cutting speed the cost of these in relation to the work done is low. The quality of the cut surface is high, potentially very high. In general, the quality of cut is such that no further preparation is required prior to welding, painting or any other process. If any of the cut material is attached to the edge of the work-piece it is easily removed. Indeed, "Underwater Plasma Cutting" was a process widely used 30 years ago, when quality of cut was one of the principal advantages claimed. In this process metal sheets were immersed in a shallow bed of water on a profile shape cutting machine.

PLASMA CUTTING UNDERWATER

Given that the plasma process has been used underwater, albeit at very shallow depths (typically 4 inches!) it might be wondered why it has not been widely adopted in underwater engineering. The primary reason is safety, particularly electrical safety, and these problems have inhibited its use.

Plasma cutting equipment typically runs at 120-200V arc voltage and will have an open circuit voltage of 250-400V. This is against a background of codes of practice in diving work favouring no more than 30 volts. It is accepted that this may not be practical, and so "safe methods of working" have to be adopted. Indeed, it is common in arc processes currently used to use 80 volts or even 100 volts, and as mentioned previously, shocks are routinely experienced. Those attempts at plasma cutting underwater previously undertaken have required very careful attention to "safe methods of working" since the voltages in use clearly have the potential to be lethal.

In developing a plasma cutting system for use underwater, we had the clear objective of eliminating any possibility of electric shock.

ELECTRICAL SAFETY - HAZARDS

In the situation where a plasma torch is cutting metal, it is very close to the work-piece. The work-piece is generally grounded and connected to one side of the power supply, and provided the cables and torch are insulated, except where the arc emerges from the torch, the chance of a diver coming into contact with the applied voltage is negligible. Thus one might consider a solution in which the torch could not be energised unless positioned close to the work-piece and ready to cut.

However, most plasma cutting systems start the process with a pilot arc, a low power arc between electrode and nozzle, which is independent of the work-piece. There are situations where it is desirable to initiate this arc prior to cutting, for example for piercing, and so a different solution was sought. We established with simple trials that the pilot arc did indeed "inject" high voltage into the surrounding water. Thus we have the possibility of exposing a diver to an electric field as shown in figures 1 and 2.

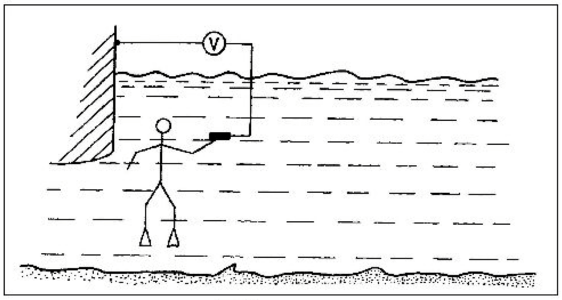

Fig.1 Operator exposed to Voltage directly

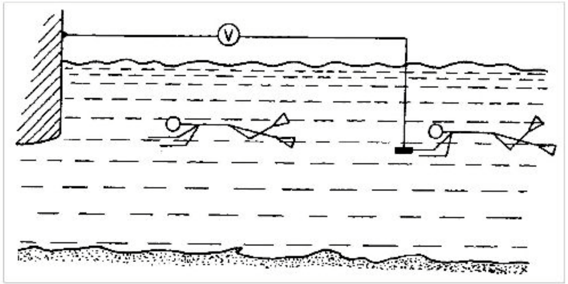

Fig.2 Another diver exposed to a Voltage field

ELECTRICAL SAFETY - SOLUTIONS

We also established with these simple trials that placing a grounded electrode into the water, close to the torch, immediately reduced the voltage measured in the water to a much safer level - from 100v - 200v to 12 volts or less. Since, by chance, the outer body of our water-cooled torch has always been a grounded metal item, even just totally immersing the torch head in the water was sufficient to reduce the voltages measured.

In considering the safety of the diver it was apparent that, surrounded by a conductive medium, it was impossible to consider all the possible paths that electricity could take to and through the body. Thus we had to contain the electricity at source. Since we had already seen that any grounded electrode placed close to the torch was effective in substantially reducing the voltages produced, it followed that if we ensured that a grounded electrode was close to the arc in the path to the diver, then any stray currents should go to this electrode and not go beyond.

This simple concept, of a grounded safety electrode close to the arc but not affecting the arc process, but in intimate contact with the water provided the basis of our prototypes for the subsequent trial program which led to the final solution now in production. (Fig. 3)

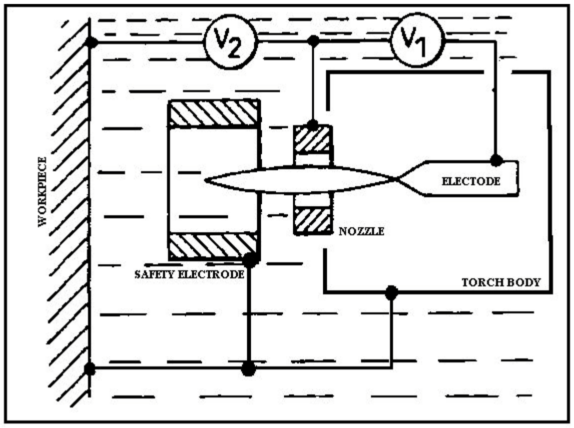

Fig.3 Grounded safety electrode and torch body.

PROTOTYPES AND EARLY TRIALS

As luck would have it, our standard torch already had a metal body, which was grounded. The grounding was monitored by a safety circuit, which ensured continuity, low voltage and current in the ground line. We also offered a stainless steel guide ring, which seemed a good choice for our safety electrode. (see Fig. 4)

Fig.4 Standard torch with grounded body and fitted with guide ring. The handle is GRP.

A further area of concern for underwater operation was the hose set, or umbilical. As well as containing the hoses for compressed air and cooling water, this contained high voltage power as well as control and monitoring cables. Whilst these are insulated, there would always be the possibility of damage, leading to exposed voltage underwater. Accordingly, the umbilical was fitted with a stainless steel overbraid, and this was connected in a loop with the guide ring/safety electrode, and the safety monitoring circuit duplicated. From the power unit the torch umbilical passed through an interface unit that provided the diving supervisor controls.

After many meetings to discuss all the safety aspects of the proposal, the first trial was at the Royal Navy School of Diving, Here we trained a number of divers in cutting on the surface, before diving into shallow water and tackling a wide range of materials, including those coated with insulating material, rust, barnacles etc. Researchers from the Institute of Naval Medicine took air and water samples, and representatives of the Health and Safety Executive observed.

There followed a series of trials with this prototype equipment, both in tanks and on a "real" job, culminating in a deep trial at Fort William. This highlighted many other requirements for safe and effective operation, which were tested in prototype form. For example, there is now a dual cutting ground system with the loop continuity constantly monitored to ensure the work-piece remains grounded. The torch handle is now of metal and part of the primary safety ground loop. These developments led finally to the requirements for the production equipment.

Fig. 5 The prototype equipment at work on a ship

Study of the economics of cutting on the “real job suggested that the plasma equipment would pay for itself in the first week!

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At the deep trial in Fort William, materials up to 40mm (1 5/8”) thick were cut at depths of up to 25m (85’). This was limited by the maximum length of our standard umbilical.

THE PRODUCTION PROTOTYPE

All the additional safety and control equipment was incorporated into a compact wheel mounted power unit. (Fig. 6) This requires only electrical power as the process air comes from an integral compressor, with a tracking regulator automatically compensating for depth. There is a small remote control panel for use by the Diving Supervisor. This replicates the power unit front panel indicators and shows correct functioning of each safety system. This is used in conjunction with the comms. system and a diver operated switch, using a slightly modified version of the usual Oxy-arc procedure. Only when all safety systems are in place is the diver switch enabled, and only when this is activated can the supervisor apply power to the torch. The cutting parameters can be monitored by the supervisor, to confirm correct operation, but no adjustments are necessary.

Fig.6 Power unit with torch and supervisor’s control.

The torch was totally redesigned to use O-ring seals in place of potting compounds, both to ensure sealing and maintain serviceability. It is now connected, as standard, to a 10m (33 feet) highly flexible umbilical, which is fitted with a custom made underwater mateable connector. This can connect directly to the power unit for use above water, or when close to the surface, or to any number of 30m (100 feet) heavy duty extension umbilicals, according to the working depth and distance from the power unit. (Fig.7)

Fig.7 The new PTU (Underwater) torch

The production prototype was tested in tank trials and other shallow diving trials, before again going to Fort William for testing to 30m. A few other demonstrations were given before the first equipment was sold.

THE EQUIPMENT INTO SERVICE

In March 2005 the first machine went into commercial operation on a project in Ulsan, South Korea. This was the construction of a large floating drilling rig, based on an existing hull that required modification. The work was being carried out by Hyundai, under the management control of Exxon, with underwater works contracted to Mermaid Offshore Services. The plasma equipment was purchased by Mermaid, on the advice of Hydroweld Ltd., who were responsible for the wet welding work.

Fig.7 The rig, Orlan, in Ulsan, South Korea.

The lower part of the hull, the mud base, was of 32mm steel. It was necessary to cut holes to allow the passage of two riser pipes, and three groups of cable ducts. All had been installed inside the mud base when dry, fitted to watertight boxes on the inside of the hull. The holes were of different shapes and sizes, but could be considered typically 1m diameter. The holes were at a depth of 15m.

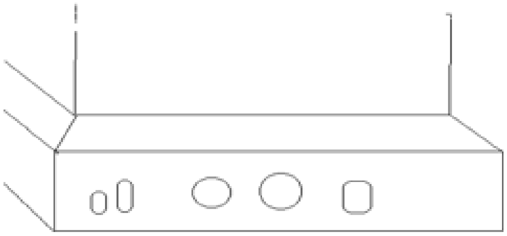

Fig.8 Holes required in mud base.

The job had been originally estimated to take 24 days using an oxy-arc process, including dressing the edges to a satisfactory standard after cutting, using grinders. However there was a reluctance to use the process on safety grounds, particularly because the watertight boxes formed an enclosed space in which oxygen and other gases would collect. The plasma process offered a way to improve safety, whilst at the same time reducing the time and cost of cutting, and providing a cut edge that needed no grinding.

Fig.9 The plasma cut edge.

As was to be expected with such new equipment, a few issues arose during the course of the project. Most equipment problems were of a minor nature and easily resolved. The more difficult problems related to difficult arc starting at depth. This problem had been encountered on the last deep trial at Fort William, and, following an investigation of the problem, modifications to the equipment had been made. These had clearly not eliminated the problem, and whilst further improvements were made in Ulsan this remains an area for further work. The solution in the short term was to scratch the surface of the electrode before each cut, but this is difficult to do effectively, and is an inconvenience in the process. We shall shortly have a pressure chamber built that allows us to simulate arc starting and pilot arc at depths of up to 50m. By reproducing the problem we are confident we shall be able to identify a proper solution in the very near future.

The other area of difficulty was in operator training. Only one of the three diver/welders had used the equipment before, and that was for about an hour in a shallow test tank. All were highly skilled wet welders and it was thought that they would quickly adapt to the process, but this was not the case. Similar problems had been encountered during the early trials with the MOD, and resolved by an intensive training session in a tank. This was not possible in this case since we were “on the job”, and the other requirements of the project meant that cutting experience could only be gained over an extended time scale. Nevertheless progress was made, and the last hole, which was the largest, was fully cut out in a single dive.

Fig.10 The last piece, out in one!

WHERE NEXT?

The original Royal Navy requirement was stated to be 50m depth, although this is now being questioned, but there would seem to be no reason why the plasma equipment in its present form should not work at this depth.

Beyond this depth is increasingly likely to be moving beyond the realms of diver operation and into ROV and other mechanised applications. There is considerable interest in the de-commissioning of offshore structures at depths of up to 200m. There would seem to be no reason why the process cannot be made to function at these or greater depths, although the characteristics of the arc, the torch and umbilical, and the power supply might well be so changed as to require substantially different equipment. In particular the arc voltage is likely to be increased.

Nevertheless, given a suitable test facility, development of suitable equipment should not present insurmountable problems.

CONCLUSIONS

It has been possible to develop plasma cutting equipment for use underwater, which allows safe use of voltages not previously considered safe. The equipment has been considerably redesigned and developed for this environment, and has proved effective in trials to 30m, and now in its first commercial application. Improvements will continue to be made but it can now be considered an efficient and cost effective tool for cutting metal underwater.

It should not be forgotten that air plasma equipment will cut any metal, quickly and economically. With ease of use and good cut quality. The basis of this equipment has been around for more than 20 years, often in remote areas (no gas required) and in arduous environments (e.g. ship breaking, scrap yards and foundries). In addressing the requirements of its safe use underwater, none of these advantages have been lost.

In every application of the plasma process the combination of high cutting speed, low process cost, and good cut quality, coupled with good operator safety, should ensure a ready acceptance of this new technology in the field of underwater engineering.

ACKNOWLEDGEMENT

I would like to acknowledge the assistance and support of the UK Ministry of Defence in bringing the prototypes to fruition and trial. I would particularly thank the dive team of Marine Salvage Unit (South) for their efforts and enthusiasm in carrying out the trials. Many other organisations have contributed significantly in various ways and I shall not attempt to name them here. They have my sincere thanks.