Cutting Technology for Decommissioning of the Reactor Pressure Vessels in Nuclear Power Plants

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1. Introduction

Lots of nuclear power plants have been decommissioned during the last 2 decades. An essential part of this work is the dismantling of the Reactor Pressure Vessel and its Internals. For this purpose a wide variety of different cutting technologies have been developed, adapted and applied. A detailed introduction to Plasma Arc cutting, Contact Arc Metal cutting and Abrasive Water Suspension Jet cutting is given, as it turned out that these cutting technologies are particularly suitable for these type of segmentation work. A comparison of these technologies including gaseous emissions, cutting power, manipulator requirements as well as selected design approaches are given. Process limits as well as actual limits of application are presented.

2. Cutting Technologies of Reactor Pressure Vessels

Dismantling the Reactor Pressure Vessel (RPV) and the Reactor Pressure Vessel Internals (RVI) of a nuclear power plant (NPP) is a challenging task [1].

Very high dose rates and a wide range of nuclides with relevant consequences for radiation protection and waste characterization have to be considered, as well as “design parameters”. The design of a RPV typically results in high wall thicknesses, complex geometric structures and materials with high mechanical and thermal load capacities.

Due to the combination of high radioactive inventory, complex design and “strong” materials specific requirements on the cutting technology are needed.

From a wide variety of field-tested cutting technologies the following techniques turned out to be specifically powerful and flexible:

- Plasma Arc cutting
- Contact Arc Metal cutting
- Abrasive Water Suspension Jet cutting

2.1 Plasma Arc Cutting

This technology was successfully used for remote controlled segmentation of RPV-internals from different Nuclear Power Plants in Europe and the United States. The reactor pressure vessel internals are typically cut under water.

Plasma gas streams out with high velocity through the plasma torch nozzle. Between the cathode inside of the plasma torch and the plasma nozzle an electric arc will be ignited and the electric energy will be absorbed by the gas in Fig. 1.

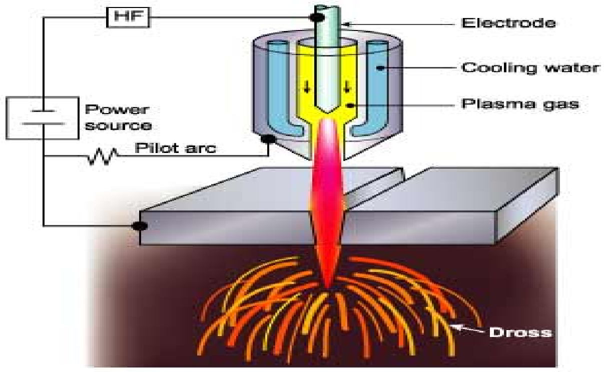

Fig. 1. Principle of plasma arc cutting.

2.2 Contact Arc Metal Cutting (CAMC)

Contact Arc Metal Cutting (CAMC) is a thermal cutting technology for underwater cutting tasks of all electric conductive materials, developed in the last two decades. The structure of the components which will be cut is not relevant. Gaps and hollow structures are not a problem. In contrast to the two other described cutting technologies, CAMC is primarily designed for dismantling tasks and can be used under water only.

The principle structure of a CAMC cutting unit is shown in Fig. 2. A carbon fiber electrode will be moved with a manipulator or guiding system slowly against the material which has to be cut. The electrode is surrounded by a strong water jet curtain.

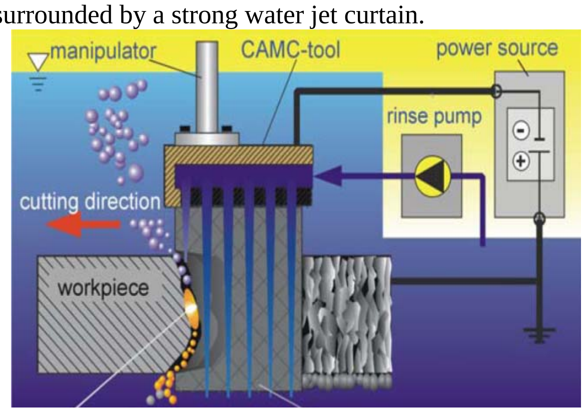

Fig. 2. Principle of CAMC.

2.3 Abrasive Water Suspension Jet Cutting

Abrasive Water Suspension Jet cutting (AWSJ) is a micro grinding process. A high pressure water jet accelerates abrasive particles and carries these particles to the material which has to be cut. The abrasive particles grind small chippings from the material and therefore produce a kerf. A pressure generator increases the water pressure up to 250 MPa. Through the main high-pressure pipeline the water flows to the suspension nozzle. A bypass-pipeline deflects a part of the water into an abrasive storage vessel. In the abrasive storage vessel slurry of abrasive particles and water are stored. The bypass water carries the slurry to the mixing valve which will join the slurry and the high pressure water to a suspension. This suspension is transported via a pipeline and a flexible high pressure hose to the cutting tool (nozzle). The nozzle accelerates the suspension again before it meets the material which will be cut. The working principle of AWSJ is shown in Fig 3.

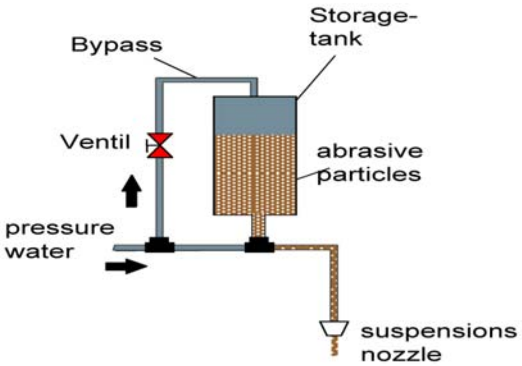

Fig. 3. Principle of AWSJ.

3. Comparison of Cutting Technology

All three cutting technologies have specific advantages and disadvantages; one aspect is the emission of gases. By using thermal cutting processes under water gaseous emissions occur. These emissions ascend to the water surface and have to be exhausted. Beside inert gases and air typically gases (nitrogen oxides, carbon oxides, hydrogen) can occur during the process. The gases are of two different origins (process gases, generated gases). An overview of the generated gaseous emissions for thermal cutting technologies under water is presented in Table 1 [2].

Table. 1. Gaseous emissions for cutting stainless steel plates.

	Material thickness[mm]	No [dm^3/min]	NO_x [dm^3/min]	CO [dm^3/min]	H_2 [dm^3/min]
Plasma Arc Cutting	50	1.9E-02	2.0E-02	<2E-2	9.4
	80	2.9E-02	3.0E-02	<2E-2	12.3
CAMC	50	8.0E-03	9.0E-03	25.7	39.7
	80	8.0E-03	9.0E-03	31.2	32.2

Typically the exhaust air from the thermal cutting processes used for segmentation of RPV or RVI are collected and filtered by specific temporary exhaust air systems. These systems should be connected to the plants stationary off gas system to ensure the following.

− A proper overall balance of aerosol activity and air flow according to the plants license requirements

− Allow control interlocks for operational and emergency shutdown procedures for both systems

− Ensure a controlled air exchange rate above the water at the working area

− Minimize the impact on the plants internal air flow balance and staggered air pressure system

Beside gaseous emissions the cutting power of each technology has to be compared. A well established parameter to compare cutting technologies is the cutting speed or feed rate for different materials and thicknesses in Table 2 [2].

Table. 2. Feed rate for Plasma Arc cutting and AWSJ for different wall thicknesses

Wall thickness[mm]	30 mm	50 mm	70 mm	115 mm
Plasma Arc feed rate [mm/min]	460	120	80	30
AWSJ feed rate [mm/min]	85	50	31	12

In nuclear engineering the practice of having multiple, redundant, and independent layers of safety systems for the single, critical point of failure is known as 'defense in-depth'. Even the determination of the cutting parameters may be part of a safe approach to the job.

Using AWSJ the jet can still have a remarkable power behind the kerf. Thus any object behind the kerf in the range of the jet may be damaged without purpose.

4. Conclusions

The presented cutting technologies Plasma Arc cutting, Contact Arc Metal cutting and Abrasive Water Suspension Jet cutting are well established powerful cutting technologies for the segmentation of reactor pressure vessels and their internals. The specific differences between each technology recommend it for specific use. Beside its advantages each technology has specific disadvantages and limits, these limits have been exceeded with each "hot use" in the past and will further exceed in the future.

REFERENCES

[1] European Commission, Dismantling Techniques, Decontamination Techniques, Dissemination of Best Practice, Experience and Know-how, Final Report, 2009.

[2] Pfeifer, W., Bienia, H., Plasma cutting in the Multi-purpose Research Reactor (MZFR) –Underwater use at steel thickness of up to 130 mm. Welding in the world – Journal of the international Institute of Welding. Vol. 51, No. 11, 2007.