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FLEXIBLE AND MOBILE ABRASIVE WATERJET CUTTING SYSTEM FOR DISMANTLING APPLICATIONS

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ABSTRACT

For the decommissioning of nuclear power plants Abrasive Waterjet (AWJ) cutting was already used successfully in dismantling activities.

High contaminated materials are normally cut by AWJ with remote controlled handling systems. However, in non- or low contaminated environments a mobile and flexible cutting system will become more important for simple cutting applications.

A first hand-controlled Abrasive Water Suspension Jet system was developed and successfully tested at the Waterjet Laboratory Hannover. Based on these experiences a new mobile and flexible cutting system for injection jets as well as suspension jets was conceived and built.

Safety requirements and ergonomic aspects of the human-machine interface have influenced the advanced conception. The developed AWJ cutting system and the results of first successful tests will be presented.

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1. INTRODUCTION

Several different cutting techniques, like mechanical, thermal or hydraulic cutting are used for the decommissioning of nuclear power plants. Mechanical cutting techniques like shearing, sawing or breaking are used to dismantle large steel and concrete structures in low contaminated areas only. Thermal or hydraulic cutting techniques are typically used in high activated environments especially for cutting under water.

In this context the Abrasive Waterjet (AWJ) has some important advantages in comparison to thermal cutting techniques, e.g. a small and flexible cutting tool with an omni-directional sharpness of the jet for cutting almost all materials. The width of cut is very small and no toxic reaction products are generated. Otherwise the process parameter must be optimized to reduce the abrasive material and respectively the secondary waste.

For cutting high contaminated materials water is normally used as a shielding medium. In these cases complex remote controlled manipulators are needed to move the cutting tool. But in non- or low contaminated environments these extensive handling systems are mostly not required. Based on these experiences in the Institute of Materials Science at the University of Hannover a conception of a hand controlled abrasive waterjet system was developed. The realization of the first prototype and the further development of a mobile cutting system are supported by the German Ministry for Education and Research.

2. ADVANTAGES OF AWJ FOR DISMANTLING APPLICATIONS

For the decommissioning of nuclear power plants often thermal cutting techniques like plasma arc cutting or oxy-fuel cutting are used. But the plasma arc is restricted on electrically conductive materials. The application field of oxy-fuel cutting is reduced to mild steel structures in atmosphere, for example the reactor pressure vessel. Furthermore the thermal processes produce aerosols, which can entrain radioactive particles and must be exhausted consequently.

AWJs were already successfully used for dismantling applications. The decision to use AWSJ or AWIJ depends on the case of operation. The advantage of the AWSJ is the high jet stability of the 2-phase jet (water and abrasive) to cut e.g. hollow structures or for tasks under water. The 3-phase AWIJ has the advantages of a continuous cutting process and short switching times.

Generally both jets can be used for an effective cutting tool with the following mean advantages:

- Small and flexible cutting tool
- Non-thermal process, no toxically reaction products
- Cutting of almost all materials
- Small kerf width
- Low reaction forces
- Low stand-off distance sensitivity

Objections regarding the abrasive material as secondary waste are not justified. The used sand has only a low fraction of potential contaminated material of the cutting kerf. So the sand can fill out cavities in existing storage containers and no additional capacities are needed. Another advantage of the AWJ technology is the possibility of separating the equipment into a high pressure generating part outside the controlled area and a cutting part with the cutting head and manipulation system in front of the workpiece.

One first example of dismantling by Abrasive Water Injection Jets (AWIJ) is the biological shield, consisting of reinforced concrete, of the JPDR in Japan [1]. Further applications are to be found in the NPP Wuergassen, Germany, where the closure head of the reactor pressure vessel was separated into 18 pieces by AWIJ [2]. In the reactor BR3 in Mol, Belgium the cover of the reactor pressure vessel with a maximum thickness of 190 mm was cut successfully at a water pressure of 400 MPa [3].

The Abrasive Water Suspension Jet (AWSJ) technology was also qualified in research programs for dismantling applications over the last years. One example is the decommissioning of the research reactor VAK in Kahl, Germany. Here the lower core shroud, the thermal shield and the reactor pressure vessel were cut by means of qualified cutting strategies and optimized parameters [4, 5].

3. REQUIREMENTS

A prototype of a hand controlled AWJ system was developed at the Institute of Materials Science in the style of a mobile wagon which is being used for cleaning and material removal applications. First successful cutting tests were done by using Abrasive Water Suspension Jet (AWSJ). But some important disadvantages of an only hand controlled system have been clarified during these tests, which are based on the cutting process.

Main requirements of a flexible and mobile AWJ cutting system are:

Cutting speed:	A constant traverse rate during the cutting process, irrespective of the surface fouling; continuously variable speed control; moving direction backwards and forwards
Cutting direction:	The cutting tool must be guided in a mechanized way. Depending on the small widths of kerf no shifting and slipping of the handling system is acceptable
Safety:	Active and passive safety components to protect the personnel; a shielding exhaust system for the reflected AWJ in case of drilling or kerfing; emergency stop
Surface conditions:	Cutting process, irrespective of the material surface, e.g. coatings, welding seams, unevenness, grooves and cracks
Ergonomic aspects:	Avoid a quasi static hand-held work of the operator; minimize the weight of the system. The risk of useless work results and accidents increases by tired personnel

Modular design:	Using AWSJ and AWIJ; horizontal and vertical cutting directions; any cutting lengths; simple handling of the cutting system; easy assembling and adapting of the system.

4. DESIGN

The main focus of the new conception was the ergonomic considerations of the man-machine interface. Regarding the main requirements and important safety aspects a flexible and universal useable AWJ cutting system was developed. Due to its modular construction, this system can be used for cutting with Abrasive Water Suspension Jets (AWSJ) as well as Abrasive Water Injection Jets (AWIJ).

A first hand-controlled AWSJ system was developed and successfully tested at the Waterjet Laboratory Hannover [6]. The general usage of this system for cutting could be demonstrated, but some important disadvantages were been shown for longer cutting lengths.

4.1 Guiding System

Because of comparatively slow traverse rates in a typical range between 10 and 300 mm/min the operator is stressed by holding the cutting tool. Hereby different forces and influences must be considered: Weight of the system, reaction forces by the AWJ as well as by torsion and bending of the hoses, vibrations of the high pressure hose. Consequently a sensitive and exact guiding of the cutting system is impossible by the operator only. Additionally an optical control of the cutting kerf is hindered by the shielding cap. Also the operator must be protected against the AWJ by means of special protective clothing.

Recapitulating a real hand-guided system has only disadvantages in comparison with a track-guided system. Because most of the dismantling applications can be realized by straight cuts, a track system was developed which can be extended arbitrarily. The guiding system consists of pluggable square pipes, a pipe support system with vacuum grippers and a motor driven slide.

The traverse slide can be moved without restriction on the square pipes. An electric driven gear motor realizes a constant and a continuously variable traverse rate. The power transmission is guaranteed by a combination of gear wheel and gear rack. The cutting tool is fixed at a slide.
The support system with vacuum grippers enables horizontal and vertical cutting directions on different materials and surface roughness.

4.2 Cutting Module

The cutting module is fixed at the traverse slide of the guiding system. By this modular conception the cutting tool can be a cutting head for an AWIJ or a just simpler nozzle holder for an AWSJ. This module is equipped with the following parts:

- The cutting head itself
- Adjustment of height, relative to the workpiece
- Connection with the shielding and exhaust module.

4.3 Shielding and Exhaust System

The shielding of the AWJ will be attained by a special protection cap. The shield is connected with the cutting heads. To reduce the dimensions of the shield, the cutting heads are integrated in the protection cap, so that one shield for each AWJ (AWSJ and AWIJ) was developed (**Fig. 1**).

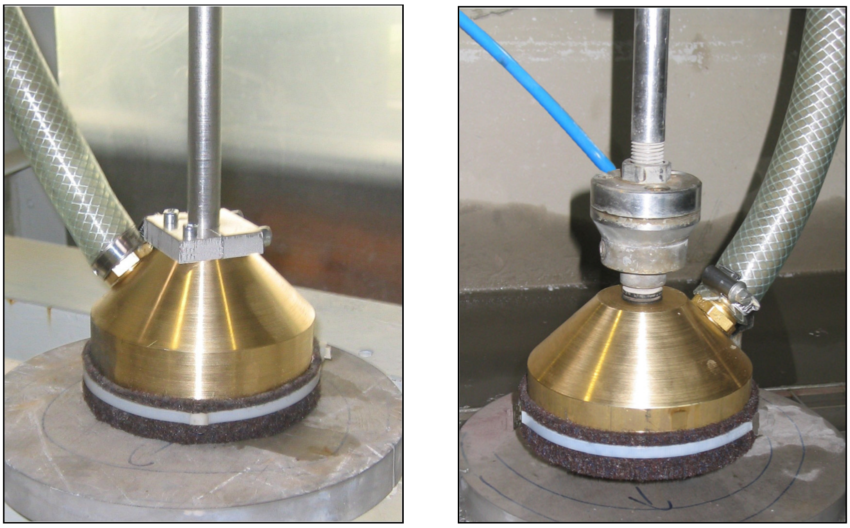

Fig.1: Shielded cutting heads (left: AWSJ; right: AWIJ)

The shields screen the reflected jet in case of drilling or kerfing. By a sealing brush between the cap and the workpiece, the reflected jet and removed material can be collected. Unevenness of the surface is compensated by the brush.

In order to prevent accumulating water, abrasive and removed material under the shield, the cavity must be exhausted during the cutting process. Because of the possibility of contamination of the exhaust suspension the exhaust system must be equipped with collecting sump. The collected material can be recycled or disposed in case of contamination.
The exhaust system is connected with the protection cap by a hose. Through a drilling in the cap the collected suspension can be exhausted.

4.4 Safety Modules

The safety components overlap with some already introduced modules of this mobile cutting system. Their tasks are the protection of the personnel and the environment.

Some important safety devices are:

- Shielding the AWJ
- Exhaust of potential contaminated suspension

- Continuous generation of a vacuum for the vacuum grippers, to avoid leakages
- Emergency stop of the high pressure pumps
- Burst discs to avoid excess pressures.

5. REALIZATION AND TESTING

Based on this conception a model of a mobile AWJ cutting system was build. In **Figure 2** the main components are illustrated. At a control unit the traverse rate and the direction of the cutting slide can be controlled. Also a mobile abrasive storage with an aperture plate is connected for an AWIJ cutting.

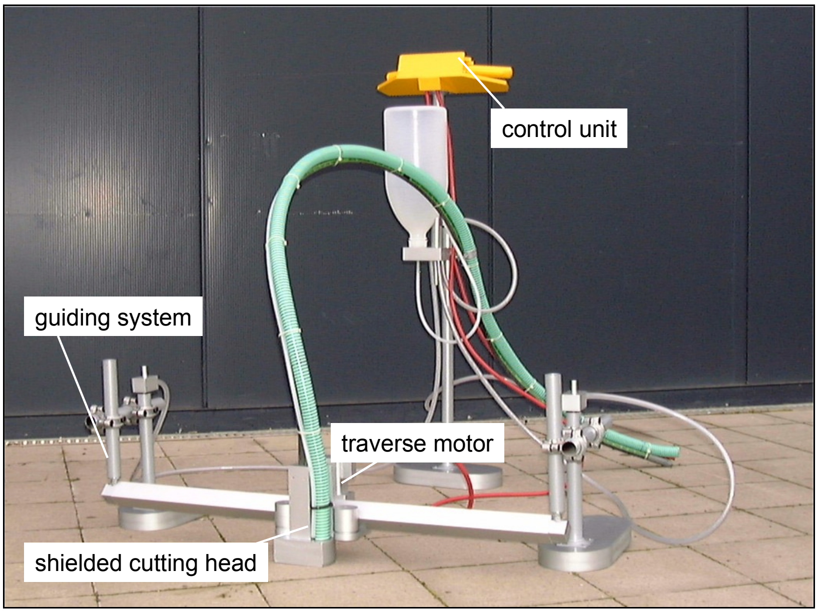

Fig. 2: Model of the mobile AWJ cutting system

Based on the designed model a prototype of a mobile cutting system was realized (**Fig. 3**).

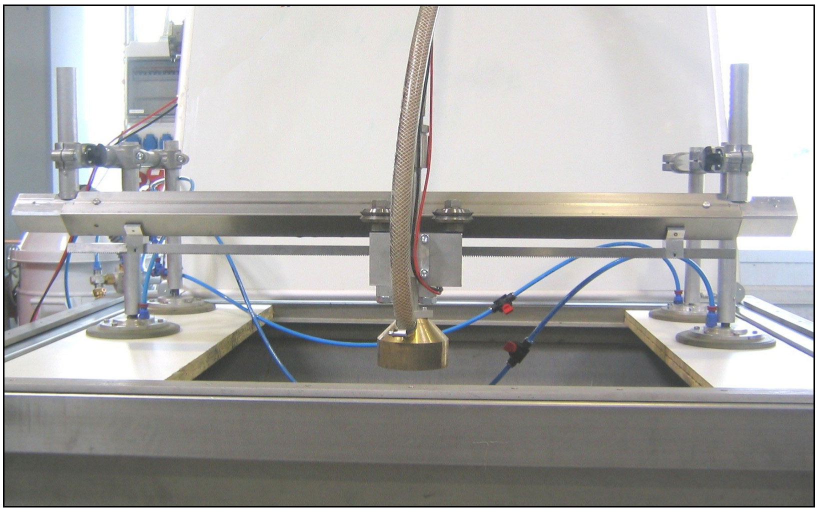

Fig. 3: Prototype of the mobile AWJ cutting system

The single hoses and cables are integrated in a package above the slide. Thereby the cutting module can be driven under the fitting of the guiding system.

The fittings of the guiding square pipe can be rotated at 90 degrees. Thus it can be enabled to cut in horizontal directions. The vacuum grippers fixed the system at the ground or the wall. In this context it is irrelevant whether the surface is dry or wet as well as the surface is magnetic or not. The stability of the guiding system can be optimized by the length of the pipe system.

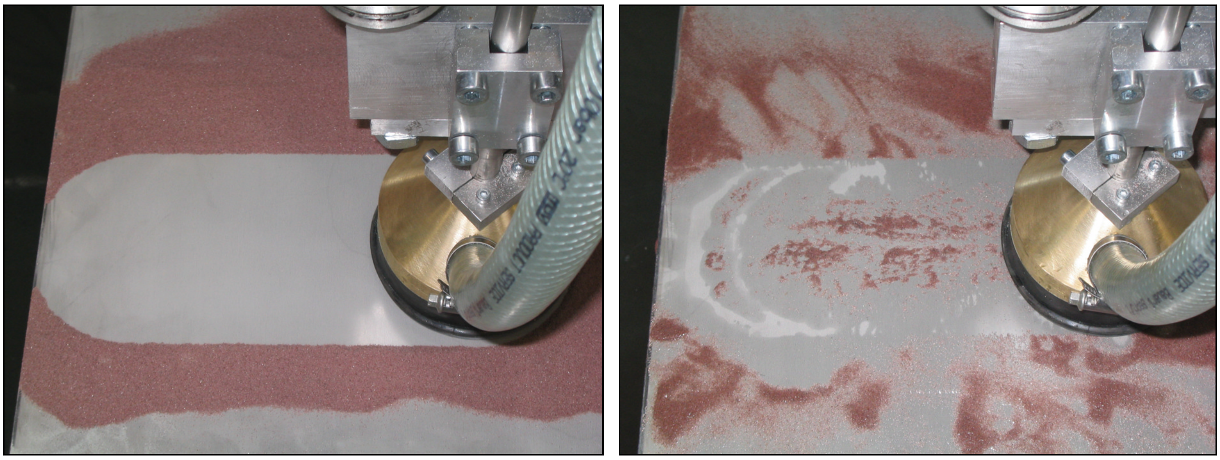

Fig. 4: Testing the exhaust system, left side: dry sand, right side: slurry

The efficiency of the exhaust system was tested with difficult application conditions. Two examples are shown in **Figure 4**. On the left side an accumulation of dry abrasive sand is completely exhausted. At a high concentrated suspension on the right side only minor residues are to be found at the surface. Under typical cutting conditions the exhaust system works without significant residues.

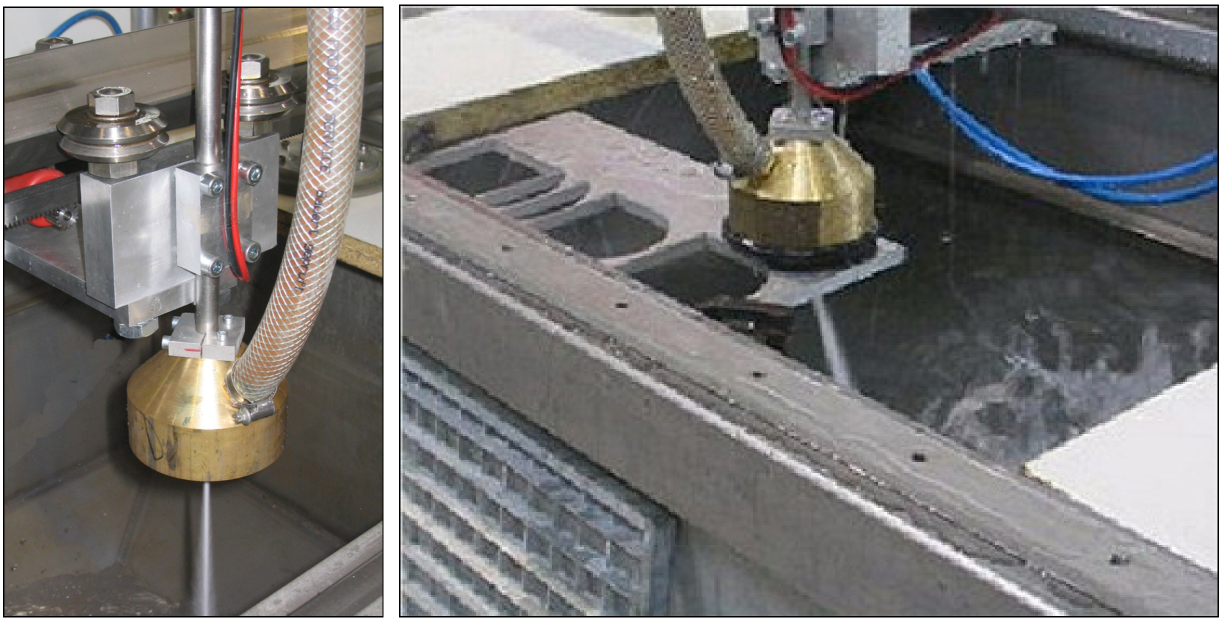

Fig. 5: Cutting with AWSJ

For the construction of this mobile AWJ cutting system the hydraulic power was limited to minimize the reaction forces and to decrease the potential of dangers for the operators. The operating parameters of the AWIJ are a maximum pressure of 200 MPa and an orifice diameter of 0.3 mm. The operating parameters of the AWSJ are a maximum pressure of 70 MPa and a nozzle diameter of 0.6 mm.

First successful cuts with the AWSJ are done in aluminium and stainless steel. In **Figure 5** the AWSJ at a pressure of 40 MPa and the cutting process in aluminium with a thickness of 10 mm at a traverse rate of 100 mm/min are shown.

5.1 Cutting Process Control

By means of shielded cutting heads the cutting process and the cutting result cannot be directly controlled by the operator. Hence, the development of an on-line monitoring system for the cutting process is necessary to control a successful dismantling of the workpiece. This system should be used to control the cutting process without time delay to detect a full or partial penetration.

The difference between kerfing and cutting through can be noticed acoustically by experienced service personnel of abrasive waterjet set-ups. But also these acoustic signals can be recorded and analysed by sensor systems. For this requirement several tests were done with diverse acoustic sensors like hydrophones, accelerometers or acoustic emission (AE) sensors.

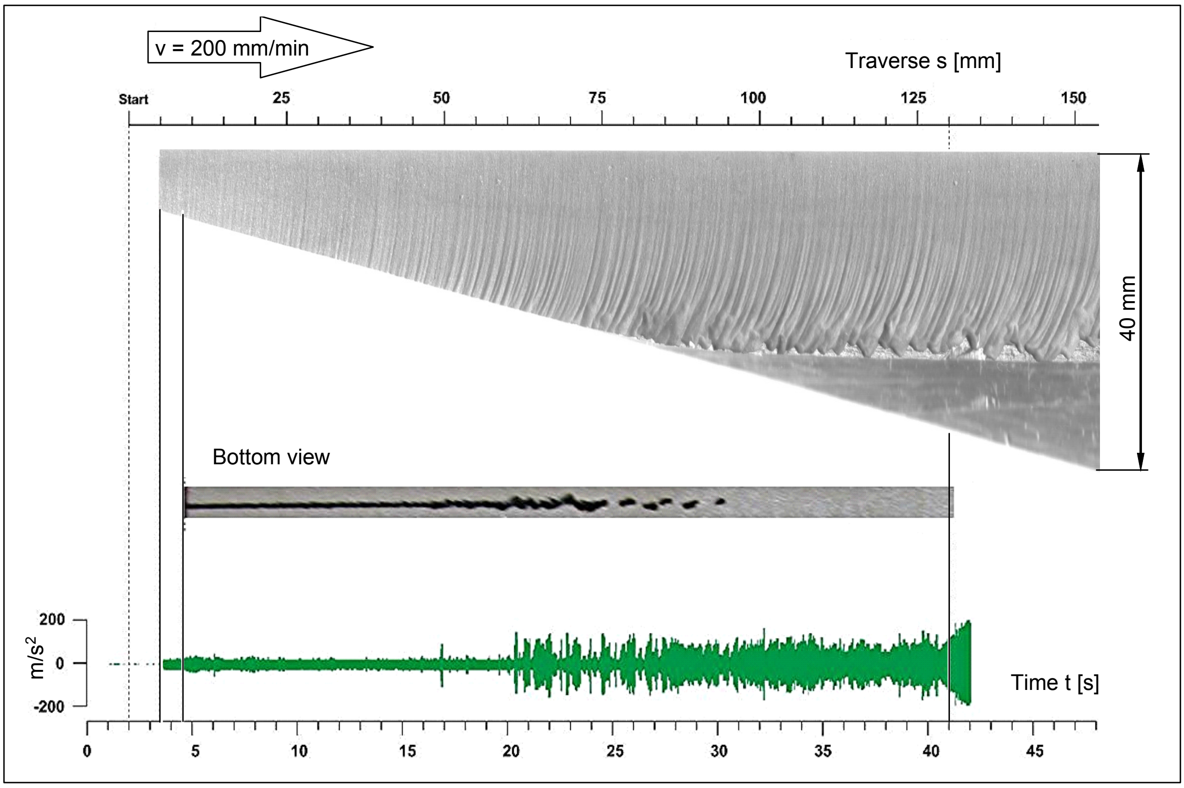

Fig. 6: Acceleration signal for cutting a wedge with an angle of 15°

One example of these tests is shown is **Figure 6**. An aluminium wedge with an acute angle of 15° was cut by an AWIJ at a constant traverse rate of 100 mm/min. The mechanical opened cutting edge, a view to the bottom side of the wedge and the appropriated acceleration signal is plotted in this figure. The transition zone between cutting through and kerfing can be inspected clearly. This zone is characterized by an alternate full and partial penetration.

The signal in the transition zone is characterized by impulsive peaks of the amplitude. However, the correlation of cutting edge and acceleration signal also shows that the first peaks indicate full penetration from 20 to 24 seconds just before the transition zone. Here, pronounced striations at the cutting edge can be identified, which has an important influence on the amplitude of the acceleration signal. Measured single peaks stand for a bad quality of the cutting edge just before the transition zone.

6. CONCLUSION AND OUTLOOK

With this flexible and mobile AWJ cutting system simple cutting applications can be done easily. The operators work is free of holding and guiding the whole handling system. Monitoring and controlling the cutting process can be done at the control unit with an adequate safety distance. The shielded cutting process can be controlled with qualified sensors by measuring vibrations and acoustic emissions at the workpiece.

A new flexible and modular design of the mobile AWJ cutting system can be used with AWSJ and AWIJ for different applications. The ergonomic and safety relevant requirements are fulfilled. Further advantages of this system are an easy and safe handling, little weight and small deviations.

Next tasks will be an optimization of the exhaust system and fixed pre-adjustments of the guiding system to enable fast movements of the system.

7. ACKNOWLEDGEMENT

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