Research Reactor MZFR, Karlsruhe, Germany
Under Water Thermal Cutting of the Moderator Vessel and of the Thermal Shield

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ABSTRACT

This paper presents the segmentation of the moderator vessel and of the thermal shield of the MZFR research reactor by means of under water plasma and contact arc metal cutting.

The moderator vessel and the thermal shield are the most essential parts of the reactor vessel internals. These components have been segmented in 2005 by means of remotely controlled under water cutting utilizing a special manipulator system, a plasma torch and CAMC (Contact Arc Metal Cutting) as cutting tools.

The engineered equipment used is a highly advanced design developed in a two years R&D program. It was qualified to cut through steel walls of more than 100 mm thickness in 8 meters water depth.

Both the moderator vessel and the thermal shield had to be cut into such size that the segments could afterwards be packed into shielded waste containers each with a volume of roughly 1 m^3.

Segmentation of the moderator vessel and of the thermal shield was performed within 15 months.

INTRODUCTION

The MZFR is a pressurized water reactor moderated by heavy water. The reactor is located at the Karlsruhe Research Center in Germany and has been part of the early German nuclear reactor development program. The reactor was designed to deliver 57 Megawatts of electricity corresponding to a thermal power rating of 200 MW. The reactor became critical in 1965 and was shut down after nearly twenty years of successful operation in May 1984.

Decommissioning of the reactor is performed in 8 steps, the seventh step includes the dismantling of the reactor pressure vessel internals and of the pressure vessel itself.

After a phase of conceptual development it was decided by the owner of the site to utilize under water thermal cutting techniques for dismantlement of the reactor vessel internals thereby taking advantage of the shielding effect by the water inside the vessel.

Plasma Cutting Technique

The under water cutting of the moderator vessel and of some thermal shield parts were performed with an advanced Kjellberg plasma cutting equipment. This equipment has been developed with respect to the requirements at the MZFR reactor which means that it had to guarantee for safe operability in 8 meter depth of water and for cutting through super alloyed stainless steel up to130 mm wall thickness. Depending on the material thickness, different fuel gas mixtures had to be used. These were:

- material thickness up to 35 mm
  plasma gas: air
  purge gas: air
- material thickness 35 mm – 130 mm
  plasma gas: Ar/H_2
  purge gas: air

The plasma torch was mounted on a five-axis manipulator system which was used to bring the torch into position. This torch carrier was equipped with an electric servo drive ensuring an exact positioning of the plasma torch at the work piece. The manipulator system was controlled by a special CNC program (Bosch OSA) by which the torch could be positioned with a tolerance of ± 1 mm. A teaching program was part of the controls. This program was used to preset the track of the torch nozzle before starting the torch operation.For teaching the instrument fixed teaching points on the vessel surface are loaded into the program. The electric sensor of the teaching head is pneumatically moved into contact with the work piece.For teaching the tracer finger swings in front of the plasma nozzle and then the coordinates of the teaching points are recorded by directing the teaching finger to these points marked by a laser pointer. The complete cutting track including the intermediate track between the teaching points is calculated by the program on basis of a special algorithm. The finger finally swings back into its neutral position behind the torch nozzle.

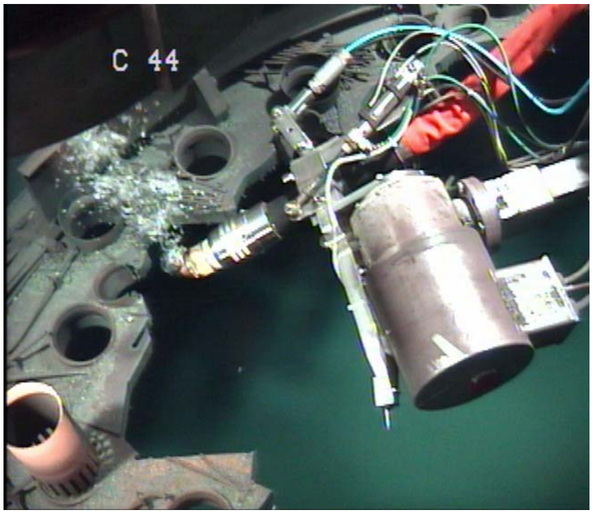


Fig.1. Plasma nozzle mounted on the endeffector of the manipulator system

Aligned along the left cylinder surface (perpendicular to the plasma nozzle) the carrier of the teaching finger can be identified. The teaching sensor is the needle at the lower end.The irregular metal structure in the upper and left part of the figure is part of the moderator vessel´s upper shell.

Segmentation of the Moderator Vessel

The MZFR reactor is in some respect a very special design. The most outstanding feature is the numerous tubes and pipes integrated into the vessel head, penetrating the upper shell of the moderator vessel and stretching down crosswise to the bottom of the moderator vessel. These tubes formerly enclosed the fuel elements. After removal of the fuel rods the guide tubes remained in the vessel. The guide tubes were finally removed at the beginning of the 7th decommissioning step. Unfortunately it was not possible to drag out all tubes by the intended procedure. Five tubes could not be withdrawn from the moderator vessel. They had to be cut above the upper vessel shell. These remaining tubes were cut with the plasma torch from the moderator vessel´s upper shell in an initial step. This was done by cutting small plates including the tube penetration out of the moderator vessel´s upper shell.

The plates with the so called separator tube hanging down from the lower side were then parked at the side of the vessel until all five tubes have been cut free. Under water handling and transfer of the tubes (plates, penetration, and tube socket) was performed by means of a hydraulic grab. Fig. 2 demonstrates the positioning of such atube assembly.

Fig. 2. Positioning of tube assemblies

The tubes themselves were finally cut into small pieces and packed into transport baskets. The transport basket was positioned on the bottom of the moderator vessel. The rod assembly was then picked up by the hydraulic grab again and positioned above the basket. By means of a hydraulic shear brought into position with a master slave manipulator the tube was cut into small segments, the segments falling down into the basket (Fig.3).

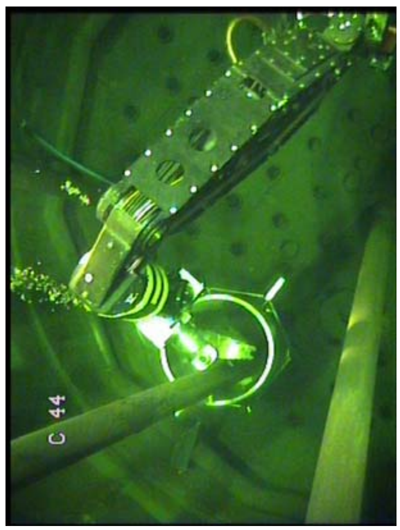


Fig.3. Crushing of an absorber tube

Loaded baskets were lifted out of the reactor vessel and lowered into a protective drum to avoid spilling of contamination. After drying the drum and the transport basket in a separate heating equipment the tube fragments together with the transport basket were loaded into shielded containers for final deposition. After the tubes and some additional capillary tubes had been removed the moderator vessel itself was segmented by means of plasma cutting.

Fig.4. Impression of the moderator vessel’s upper shell

Fig.4 gives an impression of the segmentation of the moderator vessel´s upper shell. The segmentation was proceeded in small steps, each step including the cutting of a more or less square segment. By this procedure the complete vessel was dismantled from top to bottom, mainly cutting through material with 35 to 50 mm thickness. Segmentation of the vessel including the upper and lower shell took about 13 months.

Experience with Plasma Cutting

Plasma cutting basically turned out to be a fast process. Depending on the local geometry, the material thickness, and the water depth, the cutting process was carried out with a cutting speed in a range between 90 mm/min to 600 mm/min. So the cutting process itself has never been a time limiting process. The overall time required to separate a typical segment from the moderator vessel or later on from the thermal shield has been dominated by other processes, for example by the teaching process, by positioning of grippers or of the manipulator system and by detachment of the segment. These procedures required periods of 45 min to 4 hours.

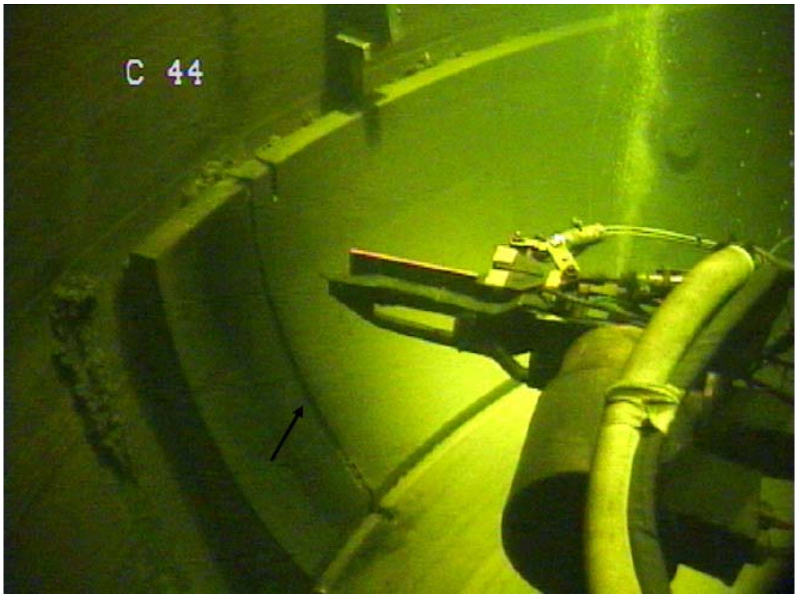
Fine particles liberated by the cutting process have been a real time consuming effect. A very powerful water cleaning unit was therefore established to provide a water exchange rate of 10 inside the reactor vessel. Despite this excellent cleaning process it usually took several hours to achieve again sufficient visibility after each cut.

Another essential aspect during the cutting operations was the time required for service and maintenance. The life time of the plasma nozzle for example turned out to be of central interest for dose exposure reasons. The nozzle´s life time depended extremely upon the geometrical situation: on plain surfaces an integral cut length of up to 40 meters was achieved while under complex conditions the nozzle assembly had to be replaced after only a few centimeters of cutting length. In order to minimize the dose occupied during replacement of the nozzle assembly, a special nozzle assembly replace kit has been developed. This module could easily be removed and refixed within a much shorter time than the standard nozzle kit.

The experience at MZFR shows that plasma cutting arrives at its limits when either the water depths or the material thickness exceeds certain limit values. It could be demonstrated that beyond 4 m water depth the maximum material thickness which can be cut by plasma is 100 mm provided that there is no additional wall behind the work piece which builds a critical gap between the two specimen. With a water pressure of about a depth of 8 m such a gap must not fall short of 25 mm, otherwise aggregation of slag in the gap or recoil of slag will damage the plasma nozzle or brings the cut to an end. Walls thicker than 130 mm turned out to be the absolute limit at 8 meters below water table for this plasma cutting system developed for this project.

Segmentation of the Thermal Shield

The MZFR thermal shield surrounds the moderator vessel. It has a cylindrical contour in its upper part but a spherical shell at the bottom. Due to this geometry the material thickness varies significantly. Along the cylinder the wall thickness is 70 mm, but near the bottom there is a transition to 130 mm. Neither the wall thickness nor the water depth interfered with plasma cutting in the cylindrical zone of the thermal shield. Therefore the upper part of the shield could be cut with the plasma torch without any problems. A backup technology however was required to segment the lower part of the shield. An advanced design of so called CAMC was finally selected as the most appropriate tool. This technique is based on the well known high current cutting with reinforced carbon electrode. By additional development it was possible to reduce the current density significantly, thereby avoiding former electromagnetic problems. The electrode was applied to the five-axis manipulator system in a similar way as the plasma nozzle. Also the



teaching process was maintained for CAMC cutting.

Fig. 5. CAMC-assembly with electrode and at its left the teaching finger in front of the lower thermal shield wall

Fig. 5 shows the CAMC-assembly with electrode and at its left the teaching finger in front of the lower thermal shield wall. Cutting the shield´s wall with CAMC was very successful. Visibility during cutting and afterwards was satisfying and much better as it would have been with high pressure water jet cutting which in principle could have been an alternative to cut the thick walls of the thermal shield. Dismantling of the thermal shield was completed within 6 weeks by end of October 2005.

SUMMARY AND OUTLOOK

Under water segmentation of MZFR´s moderator vessel and thermal shield have demonstrated that such work can be done in a reasonable period of time. It also demonstrates that appropriate equipment is now available to perform thermal cutting of thick and higher activated material even at deep water levels. Preparations are going on now at MZFR to lift and segment the massive and bulky spacer segments from the bottom of the reactor vessel. Finally, starting in early summer 2006 the reactor vessel itself is going to be cut into segments. This will finalize then the 7th phase of MZFR´s decommissioning.