REMOTE CONTROLLED IN-PIPE MANIPULATORS FOR MILLING, WELDING AND EC-TESTING, FOR APPLICATION IN BWRS

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Abstract

Many pipes in power plants and industrial facilities have piping sections, which are not accessible from the outside or which are difficult to access. Accordingly, remote controlled pipe machining manipulators have been built which enable in-pipe inspection and repair.

Since the 1980s, defects have been found at the Inconel welds of the RPV nozzles of boiling water reactors throughout the world. These defects comprise cracks caused by stress corrosion cracking in areas of manual welds made using the weld filler metal Inconel 182. The cracks were found in Inconel-182 buttering at the ferritic nozzles as well as in the welded joints connecting to the fully-austenitic safe ends (Inconel 600 and stainless steel). These welds are not accessible from outside.

The ferritic nozzle is cladded with austenitic material on the inside. The adjacent buttering was applied manually using the weld filler metal Inconel 182. The safe end made of Inconel 600 was welded to the nozzle also using Inconel 182 as the filler metal.

The repair problems for inside were solved with remote-controlled in-pipe manipulators which enable in-pipe inspection and repair.

A complete systems of manipulators has been developed and qualified for application in nuclear power plants. The tasks that must be performed with this set of in-pipe manipulator are as follows

1st step Insertion of the milling/ET manipulator into piping to the work location

2nd step Detection of the transition line with the ferritic measurement probe

3rd step Performance of a surface crack examination by eddy current (ET) method.

4th step Milling of the groove and preparation for weld backlay and, in case of ET indications, elimination of such flaws also by milling.

5th step Welding of backlay and/or repair weld using the GTA pulsed arc technique.

6th step After welding it is necessary to prepare the surface for eddy current testing. A final milling inside the pipe is done with the milling manipulator to adjust the diameter with a smooth surface according to the design.

7th step Final acceptance test by NDE, using ET method from inside and UT method from outside.

The manipulators are planned to be applied in different nuclear power plants in spring 2000.

1. INTRODUCTION

Additional measures must be taken to ensure operational reliability on piping which is subject to special safety criteria.

Owing to the very high manufacturing quality of piping which conveys a medium or retains pressure, particular attention is paid during in service inspections to the inside surface of the piping which is in contact with the medium. On the one hand, there are extensive requirements for verification of the integrity of safety-related power plant components, on the other there are requirements for regular inspection of piping from the inside. These inspections must be able to provide reproducible results.

Damage caused by wear, erosion, corrosion and crack formation may occur in the course of the piping's service file. Furthermore, undesired incrustations and deposits may form.

A visual inspection provides information on the optical condition of the inside surface of the piping or plant items. To detect material defects which cannot be located visually, suitable in-pipe inspection systems are necessary. If damage is then detected and is not accessible in any other way, it must be repaired from the inside. This repair work requires remote-control machines which can be operated with a high degree of precision and reliability. Pipe manipulators are required which can perform remote-controlled milling, welding and cleaning work in addition to US/EC-inspection and testing operations.

2. TECHNICAL STATUS OF IN-PIPE MANIPULATOR TECHNOLOGY

The power plant industry has been building and developing remote-controlled in-pipe manipulators which have been used for inspection, examination and repair of piping for over 20 years. These piping vehicles can move independently in the piping by means of special driving modules. The basic design of the machines comprises the two modules, the working module and driving module, which are connected by a flexible coupling. A cable bundle between in-pipe manipulator and control station is responsible for power and signal transfer.

2.1. Pipe manipulators for visual in-pipe inspection

Visual in-pipe inspections using a pipe manipulator give a general idea of the condition of the inside pipe surface or internals. This pipe inspection work concentrates on the detection of surface damage, which can be caused by wear, erosion, corrosion or crack formation. This damage occurs primarily in the area of weld roots, in pipe elbows and branch connections and on highly stressed items. In addition to this damage, deposits and incrustations can form at certain points, the extent of which can be established by means of visual in-pipe inspection.

Pipe inspection manipulators have been developed with which piping can be visually inspected by remote control. These pipe vehicles can be used for piping with an inside diameter ≥ 80 mm and can be operated at a speed of between 0 an 5 m/min. The standard length of the cable package necessary for power supply and for control and signal transfer is 70 m; longer cable bundles can be used without any problem.

After performance of pipe repair work it is often established that foreign matter has accumulated in the pipe. This foreign matter is located using the pipe inspection manipulators and recovered by remote control with special gripper or suction equipment. This recovery equipment is adapted to the manipulator head so that recovery manipulations can be performed within camera range. Different gripper sizes are available for recovery of different sizes of foreign matter.

Today it is standard practice-after repair work has been completed on safety-related piping for a final inspection to be performed-to ensure that all foreign matter has been removed and to document the cleanliness of the piping.

In-pipe inspections are nowadays performed using high resolution cameras with zoom. The camera system is fastened to the manipulator head and is fully mobile in all directions thanks to the pan-tilt head. An infinitely variable lighting source, is attached concentrically to the camera.

Piping inspections are always recorded on video together with the positioning data; the depth of penetration of the pipe manipulator and the angle position of the camera is displayed in the inspection recording (positioning data).

The video recording is therefore a complete document of the piping inspection and provides valuable information for subsequent inservice inspections. Furthermore, video images displayed on the monitor can be printed to provide comprehensive report documentation.

2.2. Manipulators for in-pipe machining with subsequent materials examination

Many pipes in power plants and industrial facilities have piping sections, which are not accessible from the outside or which are difficult to access. Accordingly, remote-controlled pipe machining manipulators have been built which enable in-pipe inspection and repair.

The task of the machining module is to machine the inside of piping (weld root) to permit non-destructive examination. After subsequent performance of an eddy current examination, any cracks detected are milled out. When the milling work and eddy current examinations in the pipe have been completed, the volume of material machined out must be replaced so that the original wall thickness is achieved. After welding work on the pipe interior has been performed, a combined ultrasonic and eddy current examination must be performed by remote control.
Prior to this, it must be confirmed using the TV camera that the welded surface requires no additional machining before examination.

The remote-controlled in-pipe machining modules can move independently within the piping by means of a driving module. The basic structure of the machines consists of two modules, the working module and driving module, which are connected by a flexible coupling. A control

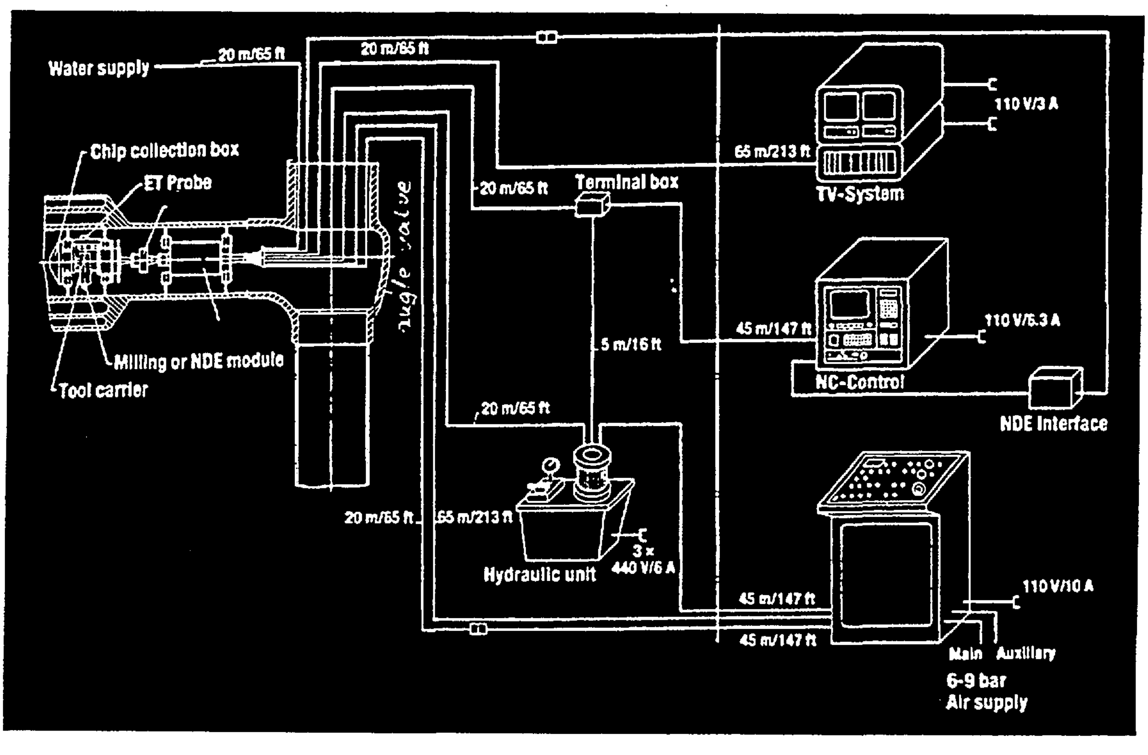


Figure 1
Equipment arrangement for in-pipe machining

system ensures reliable movement of the manipulator in the piping. Pipe elbows with a radius of curvature greater than or equal to 1.5 x D and gradients up to the vertical can be negotiated by the machining modules without any problems.

The entire milling consists of: tool carrier with examination and milling unit with suction features for chip removal, hydraulic equipment unit, camera unit, numerical control system and operator and control console for the stepping mechanism control system.

The powerful suction extractor is designed so that extraction can be performed with the milling machine at any location. An eddy current probe is integrated into the milling module which inspects the inside surface of pipes for surface cracks. This combination has the advantage that surface examination and machining can be performed with one inside manipulator. The frequency of introducing and moving the machine into the piping system is therefore reduced to a minimum.

To be able to perform the non-destructive examination of the repair weld after mechanized welding, the milling module is quickly replaced by the examination module. The driving module can therefore also be used for the ultrasonic and eddy current examinations.

With a defined interface, the position data of the examination system are available to the data acquisition and evaluation unit.

2.3. Manipulators for performance of in-pipe repair welding

The pulsed tungsten arc orbital welding method permits performance of all out-of-position welds.

The basic design of the in-pipe machine consists of two modules, the tool carrier and the driving module, which are connected by a flexible coupling. The in-pipe welding machines also satisfy the same criteria as the milling and examination machines; they can negotiate 1.5 x D pipe bends and gradients up to the vertical and perform welding in any location of the pipe. Movement and bracing of the machine in the pipe is performed in a similar manner to that used for the milling and examination machines.

The tool carrier is equipped with welding equipment for in-pipe welding tasks (repair welds and weld overlays). This consists of a GTAW torch, two welding cameras and an integrated welding wire feed.

The welding equipment consists of the following components: welding machine, welding power supply, TV unit and driving unit, control station, whereby cooling of the power source and the torch are performed by an additional equipment unit (cooling unit) in closed cooling loops.

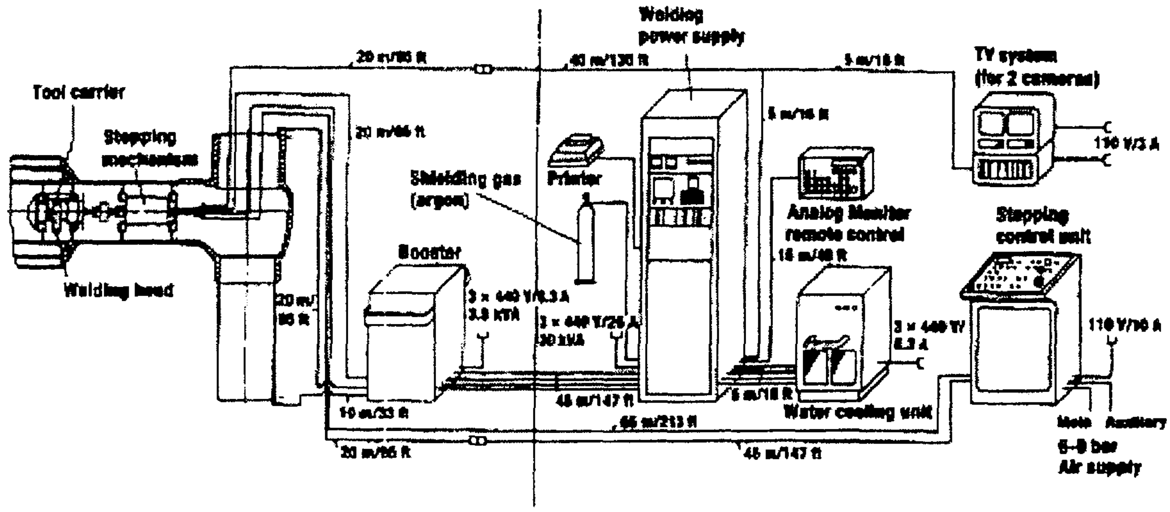


Figure 2: Equipment arrangement for in-pipe welding (sketch)

To achieve 100 % ignition reliability in the pipe, a pilot arc torch is used. This activates a small arc in the torch head by remote control which preionizes the shielding gas for the main arc. The welding head and the two cameras are water-cooled to protect against elevated temperature.

Guidance of the welding head parallel to the weld joint is ensured using a teach-in control system. Height adjustment of the welding torch in a radial direction is performed by arc control (AVC).

The operator puts in the welding parameters into the program unit of the power supply. The integral recorder monitors the important welding parameters. After centering and bracing the welding machine in the pipe, the milled out weld must be positioned with the aid of the TV positioning camera.

The inspection to determine whether the welding machine is placed parallel to the weld is performed at the weld edge and at the electrode tip above it.

The weld wire coil is installed on the front of the tool carrier. Filters which supply an adequate image both with an arc and without an arc have been installed. The welder monitors that the welding wire is being fed correctly into the molten weld pool via one of the two TV cameras attached to the welding head. With the second camera he monitors the finished weld.

Return of the welding head, lateral shift (overlapping) and positioning can be performed manually or automatically, as can restarting of the welding process. Each time the welding machine is removed the welding head must be repositioned to the weld or the bead last welded. Visual monitoring of the welding process is supplemented by position indicators and recording of current, voltage, welding speed and wire speed.

3. EXAMPLE OF A SPECIALY DEVELOPED IN-PIPE MANIPULATOR

3.1. Remote controlled in-pipe manipulators for milling, welding and EC-testing, for application in BWR's

Since the 1980s, defects have been found at the Inconel welds of the RPV nozzles of boiling water reactors throughout the world. These defects comprise cracks caused by stress corrosion cracking in areas of manual welds made using the weld filler metal Inconel 182. The cracks were found in Inconel-182 buttering at the ferritic nozzles as well as in the welded joints connecting to the fully-austenitic safe ends (Inconel 600 and stainless steel). These welds are not accessible from outside.

A remote controlled manipulator system has recently been developed which enables to repair the Inconel 182 welds of the RPV nozzles of boiling water reactors (BWR's). The detail design of the nozzle weld is shown in Fig. 1.

The system of manipulators consists of two working modules

- one working module for milling cleaning, eddy current testing and ferritic inspection
- one working module for welding

In this case, the insertion of the manipulator into the pipe is via an open pipe end, but it could also be via valves with there internals removed. Inside the pipes the manipulator can travel in horizontal as well as vertical pipes incl. the elbows.

Working module for milling

This module is equipped with the milling tool with suction features, a ferritic measurement probe and an eddy current probe .

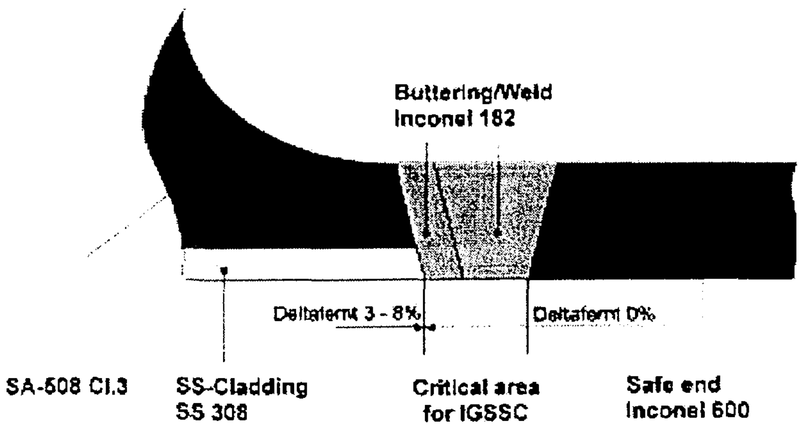


Fig. 1: Detail design of the Nozzle

The milling tool is located on a axial-, rotation- and radial slide system. With this slide system the milling tool is fully mobile in all directions, the tool is always observed via two (2) cameras. Next to the tool there is a very specialy designed suction nozzle for removal of the milling chips; this can be performed during or after the milling process.

The tool is driven by a powerful hydraulically turbine with adjustable speed.

To determine the transition line of ferritic and austenitic material the ferritic measurement examination with the eddy current probe is performed before and after repair.

To observe all the a.m. processes (milling, cleaning, ECT, ferritic measurement) two (2) TV cameras are installed at the head of the module.

The working parameters are inserted via the control station. Tool as well as probe movements can be performed with the aid of the program unit or manually.

Working module for welding

The welding module consists of the clamping unit and the welding head. The wire coil is mounted back to the tool carrier. All functional movements of the welding head are performed by electric DC motors and controlled by the power supply unit. The electrode is – similar to the milling tool – also located on an axial, rotation, and radial slide that ensures full mobility in all directions.

The power source permits precise reproduction of welding parameters. The welding parameters are stored in the control unit and the actual parameters are shown in the display.

The module for welding is clamped pneumatically inside the pipe. In the case of the feedwater nozzle the positioning of the manipulator take place behind the flow limiter (ID flow limiter 150 mm, ID pipe 300 mm).

Positioning of the electrode is accomplished by using the program unit at the control station.

The welding process is started according to the welding program.

The monitoring of the welding process via camera will be observed on the screen. One camera is for monitoring the bead and evaluating each bead right behind the puddle. The other camera is for monitoring the weld puddle and positioning the welding torch to the starting.

Task to be performed on site:

1st step — Insertion of the milling/ET manipulator into piping to the work location.

2nd step — Detection of the transition line with the ferritic measurement probe and either visually by the TV-system.

3rd step — Performance of a surface crack examination by eddy current (ET) method.

4th step — Milling of the groove and preparation for weld backlay and, in case of ET indications, elimination of such flaws also by milling.

5th step — Welding of backlay and/or repair weld using the GTA pulsed arc technique.

6th step — After welding it is necessary to prepare the surface for eddy current testing. A final milling inside the pipe is done with the milling manipulator to adjust the diameter with a smooth surface according to the design.

7th step — Final acceptance test by NDE, using ET method from inside and UT method from outside.

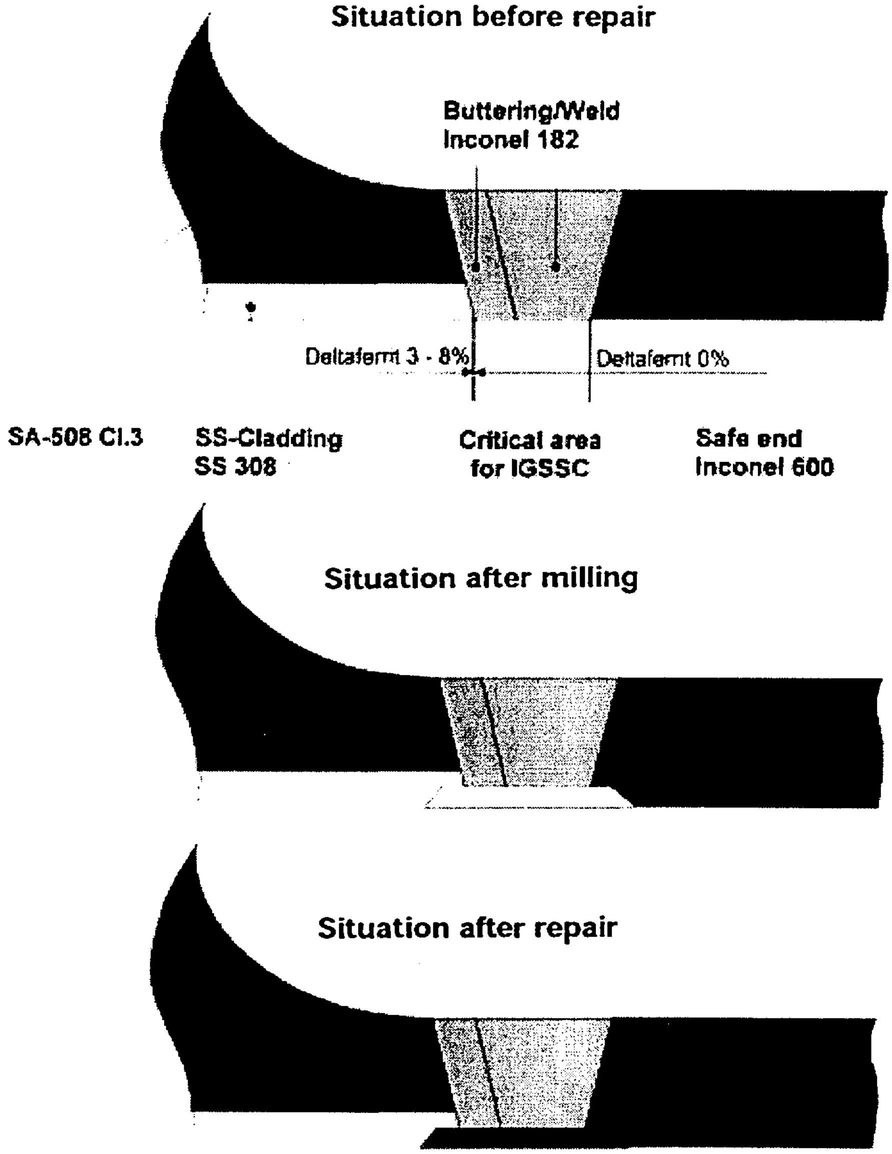
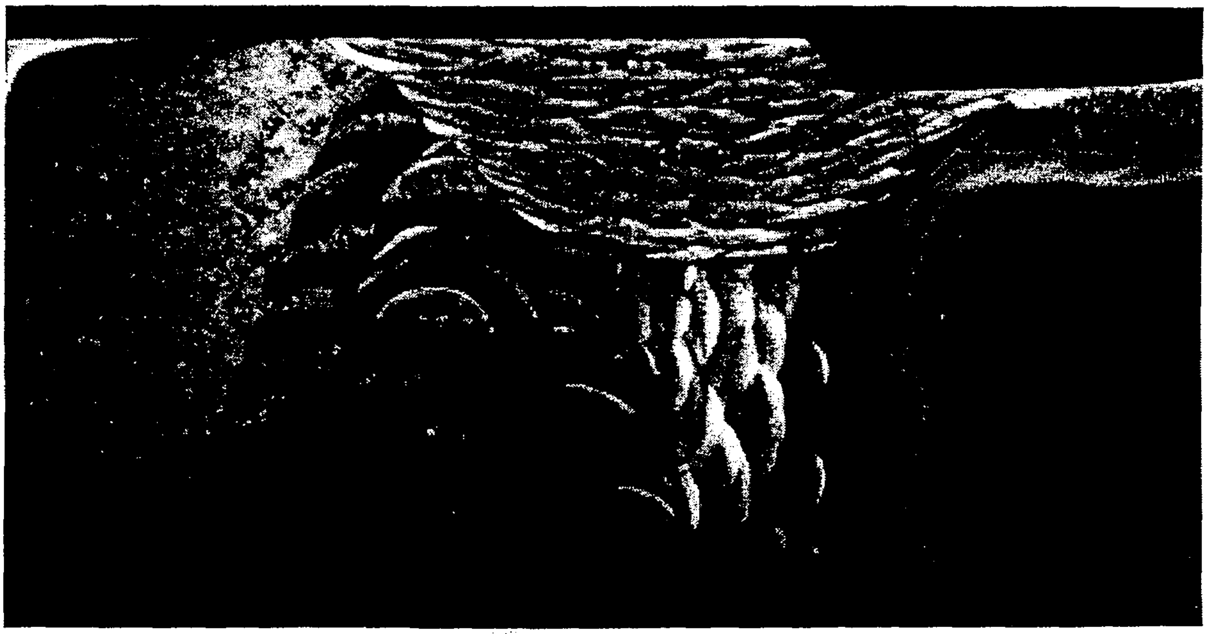


Fig. 4: Nozzle repair from inside

The following two pictures are showing the repaired nozzle weld. In the critical area for IGSSC all of the crack sensitive material of Inconel 182 is removed and replaced by Inconel 82.

picture 1: Standard repair of the nozzle weld, the Inconel 182 has been machined out up to a depth of 3 mm.



picture 2: Local repair of the nozzle weld, the depth can be up to 20 mm.

Conclusion

The knowledge acquired through on-going development work, our experience accumulated in engi-neering, equipment design and testing, and field assignments in nuclear power plants form the basis for the services and products we offer. Our manipulators are at the leading edge of development