AUTOMATED SYSTEM FOR DIAGNOSTICS AND REPAIR OF REACTOR CONTAINMENT SHELL AT BILIBINSKAYA NPP

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There exists a multitude of cases of breakdown of parts, components or complete systems because of untimely detection of their failure. Shown is the possibility of complex repair solutions in safety-critical cases, including difficult-of-access zones of industrial plants in Russia. These are complex automated and partially remotely controlled systems made in Russia and applied in the field of gas and power engineering.

Keywords: *reconditioning by welding and surfacing, gas industry and power engineering, object diagnostics, versatile robotic complexes*

There exists a multitude of cases of failure of parts, components and whole systems, because of untimely detection or difficult access to damage sources. A system, allowing performance of diagnostics of the possible weak locations and ensuring replacement or repair of the defective component, can help recondition the object. Tubular structures or vessels are often regarded as difficult-of-access objects. Access can be difficult or impossible at hazardous radiation doses, high temperatures or presence of toxic gases. Over the recent years automated and robotic diagnostic systems have been developed for such purposes. These systems are serviced by an operator using the respective remote control, and eliminate the risk for his health.

Diagnostic systems for gas and power engineering. In these industries application of complex engineering robotic systems is promising. These systems are characterized by the following capabilities: displacement over any surface, also in a forced position and in cramped space; use of any measurement systems for diagnostics; mounting the tools for repair performance, in particular, for cleaning and welding; performance of erection operations; work performance under the conditions of increased temperature and radiation.

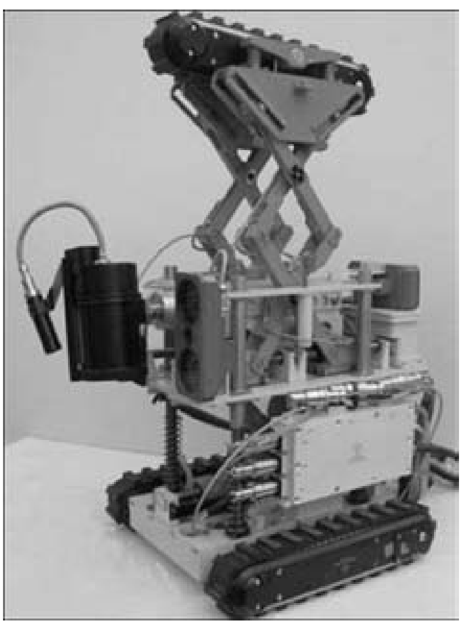

Figure 1. Diagnostic robot with electromagneto-acoustic sensor

These new remotely-controlled systems are ever wider applied for diagnostics and repair in difficult-of-access and critical in terms of safety locations. Various systems are developed for different cases. Complex remotely-controlled systems are already in place for diagnostics of the technical condition of internal surfaces of pumping and compressor stations. As a rule, such stations have straight pipes and pipes bent in many planes.

Figure 1 shows a robot capable of flexibly moving inside a pipe network, both in the horizontal and vertical direction. Using caterpillar belts mounted at an angle of 120° to each other and capable of moving relative to each other, this robot allows controlling piping with the nominal inner diameter from 700 up to 1400 mm. Maximum displacement zone is 500 m.

Owing to various explosion-safe measurement systems mounted on the robot, it is possible to obtain information about the state of the pipe inner surface, position and kind of welds based on visual inspection; possible undercuts, internal defects, as well as cracks and contamination — as a result of ultrasonic testing; surface corrosion and measurement of wall thickness or erosion depth; data on technical condition of piping, in order to determine the need for repair or replacement of pipe sections.

This system was used in 2004–2010 to examine 130 km of tube and tube plates. As a result, more than 500 various hazardous defective locations were detected and repaired. Each of them could lead to gas explosion. List of work performed in the period from

List of work performed in the period from 2008 to 2010 using the explosion-safe measurement system

Work list	2008	2009	2010
Number of inspected compressor stations;	16	9	21
Length of examined pipes, m	2411	1098	1593
Inspection scope:			
visual and measurement of welds, pcs	2411	1098	1593
ultrasonic testing of all pipes, m	23893	21516	25488
Found defects, pcs:			
in weld	205	89	249
in pipe body	671	656	1466
Repair of pipe body urgently required	273	72	75

2008 to 2010 using explosion-safe system is shown in the Table.

In St.-Petersburg training in operation of this system was organized in a test stand with built-in pipes with various defects, where features of system operation under the actual conditions can be followed (Figure 2).

Figure 3 gives pipe defects often found in practice. Improvement of automatic diagnostic system is envisaged, so as to achieve the efficiency of minimum 80 run. m/h on a length of up to 1000 km, obtaining an image in 3D format.

Application of such a diagnostic system allows considerable saving of costs, compared to the method, when the damaged pipe sections are uncovered with all the respective work stages. Experience accumulated at development of a complex remotely-controlled diagnostic system for gas industry and power generation, can be used at development of automated systems for NPP diagnostics and restoration.

Development of the technology of diagnostics and repair of NPP equipment using welding. During the scheduled inspection of reactor 1 at Bilibinskaya NPP, Russia (Figure 4) defects were found in the so-called biological shield, enclosed into external and internal steel shell.

Figure 2. Test stand with artificial and natural defects

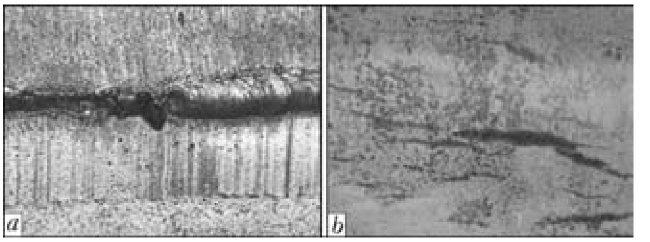

Figure 3. Kinds of defects: *a* — joining defects in the weld root (pipe D = 1000 mm, s = 16 mm); *b* — crack-like defect of 1.5–4.0 mm length (pipe D = 10000 mm, s = 14 mm)

As we are talking about space critical in terms of safety, difficult-of-access and presenting the radiation hazard, a robotic technology was developed, allowing performance of repair work on the steel shell from the inner side of biological shield. Power of Bilibinskaya NPP is 48 MW. This is the smallest NPP in the world working in permafrost zone. It has four boiling-water graphite channel reactors [1]. Shutdown of Bilibino-1 reactor, put into operation in 1974, is scheduled for 2019. Inner shell of biological shield is made from unalloyed steel S 255 (St.3) 20 mm thick. The defined objective was to examine the inner wall of the shielding vessel for defects, classify and eliminate them. Process of flux-cored wire gas-shielded welding was selected at performance of repair first of all because this process lends itself easily to automation. Repaired locations were to guarantee leak-tightness. In connection with the need to weld up defective locations in forced positions in space, seamless rutile flux-cored wire with rapidly-solidifying slag was used.

All the applied systems, instruments and filler materials needed clearance by the respective bodies of nuclear power engineering of the Russian Federation. Comprehensive preparation was performed before the start of repair. Repair included surface diagnostics for possible defects; determination of the kind of defects; preparation of defective locations for subsequent building up by cladding; and performance of cladding.

Full-scale test stands were manufactured for trial experiments, allowing retrofitting of individual work stages and determining all the needed control parameters (Figure 5).

Figure 4. Appearance of reactor 1 of Bilibinskaya NPP [2]

Figure 5. Test stand from steel S 223 of 20 mm thickness

To measure the thickness of steel wall metal layer, damaged by corrosion, an electro-magnetoacoustic sensor was used which functions without the couplant. Special well-illuminated chambers were used for visual inspection.

For the working zone a specialized remotely-controlled robot was designed (Figure 6), which carries the measuring and work tools. Robot, consisting of approximately 1000 individual parts, can move vertically or horizontally, recognize and overcome various obstacles, for instance, reinforcement in the wall.

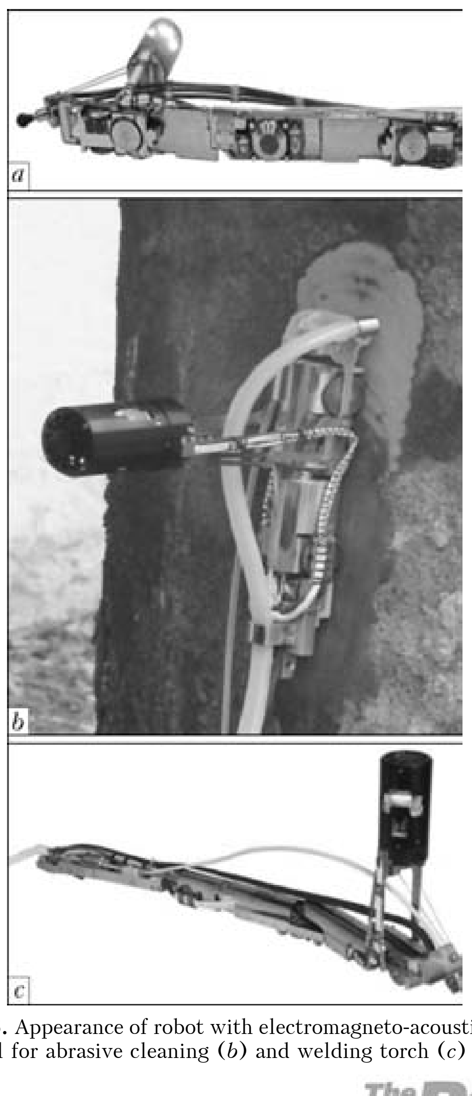

Figure 6. Appearance of robot with electromagneto-acoustic sensor (*a*), tool for abrasive cleaning (*b*) and welding torch (*c*)

The task of ensuring the wire feed turned out to be the most difficult one. First, the flux-cored wire had to be transported for an up to 20 m distance, and, secondly, stable arcing had to be guaranteed. All together 400 samples were welded and tested at the Departamental Institute of Nuclear Industry.

As a result, the following optimal parameters of welding mode were proposed: wire feed rate of 2.7–3.5 m/min; welding current of 110–130 A; welding voltage of 21 V; welding speed of 4 cm/min; oscillation amplitude of 50 mm for upward fillet weld, and 20 mm in the downhand position; shielding gas being M1 (Ag + 25 % CO_2); weld reinforcement of 2–4 mm; deposition rate of 1.5–2.0 kg/h.

In connection with welding cable (diameter of 16 mm), specific for conducting the welding process, the arc could only run for 1.5–2.0 min, after which cooling was required. Figure 7 schematically shows the working situation at repair of steel wall by cladding.

After preparatory operations, concerning mainly, the sequence of repair performance, the system was applied for the first time at Bilibino. First the internal steel wall was examined. Analysis of the found defects showed certain deviations from values specified by the customer when defining the repair task. It was found that layers of up to 5 mm thickness came off as a result of corrosion, instead of maximum 2 mm. Distance from biological shield to reactor case is just 408 instead of 420 mm. Height of steps between individual sections of steel plates on the inner wall was 10 instead of 18 mm. In addition, tubes for thermocouples, not indicated in the documentation, were found in the robot lock zone. All the mentioned differences required mandatory adaptation of the used equipment. For this reason the robot, shown in Figure 6, *b* with a tool for abrasive cleaning, was additionally created. Speed of

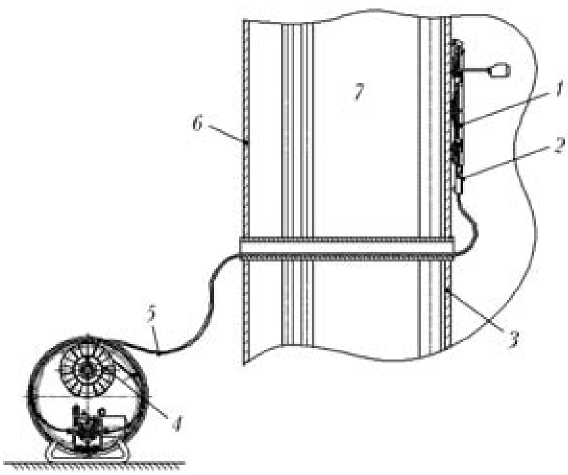

Figure 7. Diagram of welding on the inner wall of biological shield: *1* — repair robot; *2* — device for uniform wire feed; *3*, *6* — inner and outer steel wall, respectively; *4* — wire feed mechanism; *5* — wire feed channel; *7* — biological shield from concrete

Figure 8. Appearance of defect 11 — crack network in the connecting weld between two sections (×2)

Figure 9. Defects eliminated by cladding on inner steel shell (marked section of the surface, where the network of cracks was rewelded, is shown in Figure 8)

surface cleaning by this system increased greatly. In addition, it was now possible to clean the surface after welding, from slag and remains of wire, stuck to it at ignition, thus increasing the air-tightness of the deposited sections. At the first cleaning of the surface of biological shield inner wall (2.5 m^2) the system found 21 defect. As at any technology application the diagnostic system without abrasive cleaning failed to detect ten surface defects, the advantage of an improved cleaning system is obvious. Cracks found in the weld between two sections of the inner steel wall (Figure 8) can be eliminated by cladding. As the defect was not completely eliminated after deposition of the first cladding layer, the process had to be repeated. Here, a new concept of abrasive cleaning of the surface was used.

Surfaces of the damaged area after welding, shown in Figure 9, were repaired by cladding.

In October 2010 the department of ROSATOM Concern, responsible for operation of the system at Bilibino, performed acceptance of repair work and commissioned the reactor.

CONCLUSIONS

1. A versatile robotic small-sized unit was developed, which can move in a forced position in a closed space at exposure to radioactive radiation. This system can be applied for diagnostics, wall thickness measurement, visual inspection, welding or surfacing, in order to ensure tight joints, performing work on cleaning the surface from slag, corrosion damage or paint.

2. The developed system is used to perform cleaning of the surface of inner steel wall of biological shield of 2.5 m^2 area. Here 10 or more cracks were found, which were repairable.

3. Technology of repairing cracks and sealing the defective locations by single- or multilayer cladding was developed.

4. Experience acquired at repair will be the basis for performance of further work on ensuring the safety of Bilibinskaya NPP, as well as other NPP of ROSATOM Concern.

1. *http*://atomas.ru/rosatom/safety-gp.html
2. *http*://atomas.ru/rosatom/bilibino.html