DEVELOPMENT AND APPLICATION OF THE ULTRASONIC TECHNOLOGIES IN NUCLEAR ENGINEERING

Authors:
Лебедев Олег (Lebedev Oleg), ООО «Новотех-ЭКО», eco@alexplus.ru
Лебедев Николай (Lebedev Nikolay), ООО «Александра-Плюс», mail@alexplus.ru
Доцент Гаврилов Юрий (Gavrilov Yuri), Вологодский Государственный Университет, gavr10@mail.ru
Доильницын Валерий (Doilnitsyn Valery), СПбГТИ(ТУ), doilnitsyn@mail.ru
Акатов Андрей (Andrei Akatov), СПбГТИ(ТУ), andrey_akatov@mail.ru

Abstract: *Efficiency of some traditional chemical technologies in different areas could be significantly increased by adding ultrasonic treatment. For example, ultrasonic treatment was found to improve make-up water systems, decontamination procedures, etc. Improvement of traditional chemical technologies with implementation of ultrasonic treatment has allowed to significantly reducing water waste, including harmful species and radioactive products.*

The report shows the examples of the recent ultrasonic technology development and application in Russian nuclear engineering. They are as follows:

- Preliminary cleaning of surfaces of in-pile parts (e.g. control sensors) prior to their assemblage and welding
- Decontamination of grounds and metal surfaces of components with a complex structure
- Decrease in sliding friction between fuel rods and grids during VVER reactor fuel assembly manufacturing
- Removal of deposits from reactor fuel surfaces in VVER-440s
- Increasing the density and strength of pressed sintered items while making fuel pellets and fuel elements, especially mixed-oxide fuel

Surface cleanness is very important for the fuel assembly manufacturing, especially prior to welding. An ultrasonic technology for surface cleaning (from graphite and other lubricants, oxides etc.) was developed and implemented. The ultrasonic cleaning is applicable to the parts having both simple shape and different holes. Ultrasonic technology has allowed to improve the surface quality and environmental safety.

Ultrasonic treatment appears to be expedient to intensify the chemical decontamination of solid radioactive waste from grounds of different fractions to metallic components. Ultrasonic treatment reduces the decontamination process duration up to 100 times as much. Excellent decontamination factor was received even for the ground fractions below 1 mm. It should be noted that alternative decontamination techniques (e.g. hydraulic separation) are poorly applicable for such ground fractions. Parameters for ultrasonic treatment were optimized based on both traditional cleaning fluids (acids, alkali, etc.) and modern detergents.

Industrial tests showed that the ultrasonic fuel tube treatment has resulted in fuel assembly rack shape improvement, stress mitigation, and reduced assembly deformation during the manufacturing process. Ultrasonic treatment has allowed reducing about up to twice as much the forces occurring during insertion of tubes into spacer grids and fuel rods into the assembly racks.

The crud deposition on fuel rod surfaces is a challenge for nuclear reactors. An effective ultrasonic cleaning technology has been developed for VVER fuel of the Novovoronezh NPP. Its use resulted in higher reactor reliability and increased fuel assembly operation time.

Ultrasound application for moulding powder materials for pressing increases the sintered ceramics density and strength, and improves the surface quality. The technology was tested with zirconium oxide powder and was recommended to be used to manufacture fuel pellets with hard-to-press materials, e.g. MOX fuel. Moreover, ultrasonic treatment appears to be expedient for manufacturing of fully filled fuel elements.

Introduction

Russia has significant experience of ultrasonic technologies development and application in nuclear power engineering. A wide range of problems was solved due to development and implementation of unique ultrasonic equipment within the long-term cooperation between Alexandra Plus Ltd., OJSC NIKIET (the organization of Reactor Assembly Engineering), OJSC Concern Rosenergoatom (the organization operating Russian NPPs) and other enterprises of the sector. The report covers examples of successful application of various ultrasonic technologies in domestic nuclear engineering including metal nuclear waste and soil decontamination.

Widening of UST usage based on piezoelectric effect is very promising in various industry sectors. The following results of UST development and application in nuclear engineering is of great importance:

- preliminary cleaning of part surfaces prior to their assemblage and welding;
- decontamination of grounds and metal components of complex structure;
- decreasing sliding friction while manufacturing fuel assemblies of VVER-1000 reactors;
- removal of defective fuel elements from a fuel assembly with minimum damage during the operational period;
- operational cleanings of VVER-440 fuel assemblies aiming at removal of deposits from fuel elements surfaces;
- increasing density and strength of pressed sintered items while manufacturing fuel pellets and fuel elements, especially of MOX fuel.

Surface cleanness plays the key role in the assembling and welding. Alexandra Plus has developed and implemented technical processes of ultrasonic surface cleaning from various contaminations, including lubricating fluids, graphite lubricants, oxides, etc. Ultrasonic cleaning can be applied to items of simple configuration as well as to items having internal hollows. It should be mentioned that these processes allowed to improve the quality of treated surfaces as well as to make a significant contribution to environmental safety at workplaces due to non-toxic operational solutions. Ultrasonic treatment is very practical for intensifying chemical decontamination process of metal parts and grounds of different fractional composition.

Alexandra Plus has patents for all its inventions whose authors are more than 50 leading experts both in the sphere of ultrasonic technology and fields where this technology is applied. The firm's engineers have developed more than 100 ultrasonic heads which are used in more than 400 types of equipment. The equipment operates in 9 countries. The characteristic feature of the firm's developments is a wide use of resonance effects in ultrasonic oscillation range which allows to increase significantly the equipment efficiency and decrease power consumption. Among the firm's clients are leading industry enterprises from Russia and neighboring countries. Alexandra Plus's most prominent partners are Concern Rosenergoatom and its branches including Novovoronezh, Beloyarsk and Kalinin NPP as well as other enterprises of nuclear fuel cycle. Alexandra Plus conducts active cooperation with Russian leading research centers and supplies them with test ultrasonic equipment.

Main directions of ultrasonic technologies implementation include:

- ultrasonic cleaning;
- solid radioactive waste decontamination;
- ore dressing;
- drinking and waste water disinfection;
- metal crystallization;
- plant materials extraction.

Ultrasonic Cleaning Technologies

Ultrasound usage allowed to increase cleaning quality of various equipment and separate elements in the spheres of general and nuclear engineering as well as in many others. Equipment samples are shown in figure 1.

Fig. 1. Ultrasonic cleaning equipment

In figure 2 one can see an equipment sample for ultrasonic cleaning of wire for reed switches manufacturing. Five wire strings go simultaneously through the ultrasonic section where the high quality cleaning process at a speed of 400 m/m is intensified due to focused ultrasonic exposure and resonance oscillation of the wire itself. A similar cleaning unit for welding wire of titanium and special alloys was supplied to NIKIET in 2006.

Fig. 2. Wire ultrasonic cleaning unit for reed switches manufacturing

Fuel Assembly Ultrasonic Cleaning Technology

Nuclear reactor operation may possibly lead to deposit accumulation on outside surfaces of fuel elements especially in case of imperfect water chemistry systems. In order to provide reliable fuel operation, fuel assemblies are cleaned. Cleaning of VVER-440 fuel assemblies is complicated by presence of shrouds. Due to intensive radiation cleaning is to be conducted in the at-reactor fuel storage pool. The Novovoronezh NPP is supplied with a resonance shroud head 3 m long and Ø 22 cm designed by Alexandra Plus. It made possible removal of deposits from fuel assemblies which provided their further reliable operation in the reactor. This positive experience is significant for solving similar problems at other NPPs with VVER. As it is known, previous mass fuel assembly cleaning of VVER-440 was conducted using western technologies at the Paks NPP, Hungary, it was connected with a significant risk taking into account emergency destruction of 30 fuel assemblies with negative consequences. In comparison with foreign equipment this unit reduces power consumption and cleaning duration of shroud fuel assemblies.

Fig. 3. Ultrasonic cleaning equipment for NPP fuel assemblies with VVER

Ultrasonic Technologies Implementation for Manufacturing Fuel Assemblies

Ultrasonic technologies appeared to be very valuable for improving nuclear reactors fuel manufacturing. Application of ultrasonic oscillation on fuel element tubes provided considerable friction reduction while assembling (figures 4 and 5).

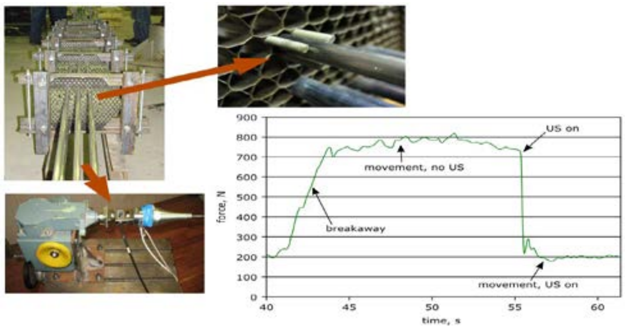

Fig. 4. Friction reduction due to ultrasonic treatment while assembling

The results of industrial testing of ultrasonic resonance treatment of tubes showed better geometric structure of fuel assembly racks, stress relaxation and lesser fuel assembly deformation when in operation. The testing process included comparison of force applied while assembling channel tubes with spacer grids with ultrasonic treatment and without it. A similar technology used for assembling fuel elements into a rack allowed to significantly reduce force appearing while assembling (figure 5).

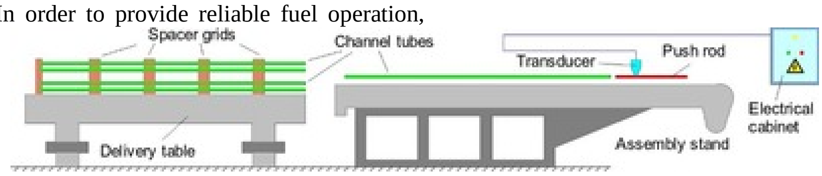

Fig. 5. Ultrasonic equipment for friction reduction for fuel assemblies manufacturing

Ultrasonic Technologies Implementation for Reactor Fuel Manufacturing

Ultrasonic treatment provided better moulding quality for nuclear reactor fuel manufacturing (figures 6 and 7).

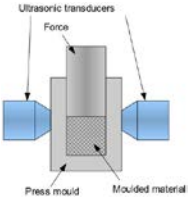

Fig. 6. Diagram of fuel pellets moulding

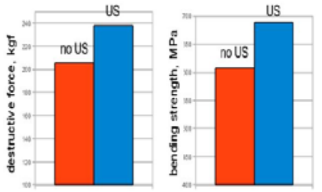

Fig. 7. Ultrasound (US) influence on fuel pellets strength characteristics while moulding

Increase in density and strength allows to recommend ultrasonic treatment for manufacturing fuel elements of difficult-to-extrude materials, e.g. manufacturing pellets of MOX fuel. Besides, ultrasonic treatment of fuel element tubes is very useful for manufacturing fuel elements with full filling.

Ultrasonic Technologies Implementation for Metal Crystallization

Ultrasound efficiency in metal crystallization process is confirmed by the results comparison of failure patterns fractographic studies (figure 8). Ultrasonic treatment increases zirconium alloy resistance to intergranular corrosion. The main difficulty of this technology implementation is ultrasonic oscillation transmission into a melt through the walls of a copper Junker's mould during vacuum arc remelt.

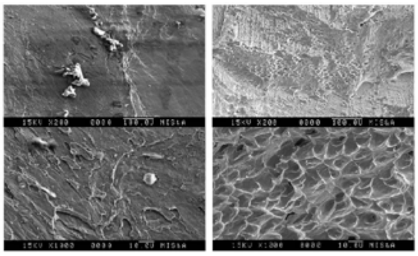

Fig. 8. Ultrasonic treatment (right) breaks oxide inclusions

Ultrasonic Technologies for Drinking Water Production and Waste Water Disinfection

Joint application of ultrasound and ultraviolet rays is efficient in drinking water production and waste water disinfection (figure 9). This technology can be especially useful for water treating systems of nuclear stations. Resonance effect use lifts restrictions on productivity and equipment power consumption.

Fig. 9. Joint treatment of drinking and waste water with ultrasound and ultraviolet

Ultrasonic Technologies for Decontamination of Metal Parts and Grounds

Ultrasonic technologies provided efficient decontamination of metal parts, including spent fuel assembly shrouds (irradiated fuel assemblies) (figures 10—12). Main cleaning methods of large parts include the use of big baths, submersible modules and contact treatment.

Fig. 10. Cleaning methods of large radioactive parts

Fig. 11. Pilot unit for ultrasonic decontamination in the Andreeva Bay

Fig. 12. Ultrasonic bath for irradiated fuel assembly shrouds decontamination

Ultrasonic technologies tests showed that initial beta contamination of irradiated fuel assemblies decreased from 500—16 000 particle/(cm²×min) to less than 16 particle/(cm²×min) and the average decontamination factor was 850. This resulted in generation of only solid radioactive waste – two 200-litre barrels with concrete compound for 25 t shrouds and 1 filter-container (200 l) without any liquid waste. Due to decontamination shroud metal becomes acceptable for further use and remelting. Decontamination expenditures were 12 rub/kg at the scrap price of 40—50 rub/kg (in 2007). Figure 13 displays fragments of irradiated fuel assembly shrouds before and after decontamination.

Fig. 13. Fragments of irradiated fuel assembly shrouds before (left) and after decontamination (right)

Figure 14 dipicts a NO-145 decontamination unit produced for NIKIET, which was used for solid radioactive waste tests at the Beloyarsk NPP (figures 15 and 16).

Fig. 14. NO-145 decontamination unit used for solid radioactive waste tests at the Beloyarsk NPP

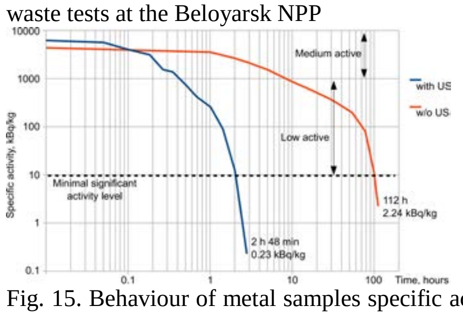

Fig. 15. Behaviour of metal samples specific activity during test decontamination at the Beloyarsk NPP

Ultrasonic treatment implementation allows to greatly shorten decontamination process. Positive results were obtained during ground decontamination of less than 1 mm fraction. Other methods (e.g. hydroseparation) are unable to provide decontamination of such fractions. The testing process included search for the best treatment parameters using both conventional cleaners (acids, alkalis, etc) and modern detergents with a wide range of pH index variation 2 ≤ pH ≤ 12.

Fig. 16. Solid radioactive waste fragments before (top) and after decontamination (bottom) using conventional technologies (left) for 112 h and ultrasonic treatment (right) for 2.8 h

The existing equipment provides a possibility to create a mobile unit for decontamination or/and chemical cleaning of metal surfaces including those of complex structure (figure 17).

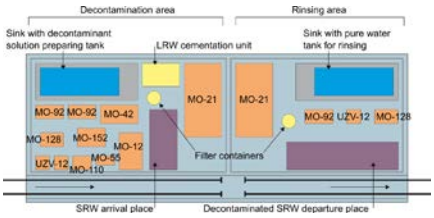

Fig. 17. Draft of a possible decontamination unit for metal parts

Figure 18 dipicts a MO-128 decontamination unit (mobile bath with a detergent circulation system) supplied to the All-Russian Research Institute for Inorganic Materials.

Fig. 18. MO-128 decontamination unit in the All-Russian Research Institute for Inorganic Materials

Figure 19 displays a MO-152 unit with a 2.2 m³ ultrasonic bath produced for the Kalinin NPP.

Fig. 19. MO-152 decontamination unit at the Kalinin NPP

Figure 20 displays a MO-92 ultrasonic bath for parts with the mass up to 350 kg.

Fig. 20. MO-92 ultrasonic bath in the Luninets locomotive depot (Belarus)

In figure 21 one can see the biggest ultrasonic bath (MO-21) in the world with the volume of 19 m³ operating in the Khabarovsk locomotive depot for cleaning details of up to 5 m long and 7 t heavy. Figure 22 depicts a MO-12 ultrasonic unit with joint ultrasonic and spray cleaning, detergent heating and filtering for parts with mass of 100 kg.

Fig. 21. MO-21 ultrasonic bath for locomotive wheeled carts in the Khabarovsk-2 locomotive depot

Fig. 22. MO-12 ultrasonic decontamination unit

In figure 23 one can see an ultrasonic decontamination unit for fluid radioactive waste storages. The remotely controlled ultrasonic module is moved by currents created by ultrasonic heads. As storage walls are cleaned, fluid radioactive waste level is decreased; at the final stage decontamination of the pool's bottom is conducted due to the use of ultrasonic heads on the unit's bottom.

Fig. 23. Ultrasonic decontamination of fluid radioactive waste storages

Figure 24 displays ultrasonic ground decontamination. The tests were jointly conducted with NIKIET in the MosNPO Radon (Scientific Production Association).

Fig. 24. NO-180 pilot ultrasonic unit for ground decontamination

Conclusions

The analysis of the Russian experience of ultrasonic technologies development and implementation in nuclear engineering indicates high prospects of its application in such spheres as: fuel assembly cleaning from deposits, equipment and ground decontamination, fuel elements and assemblies manufacturing, drinking water production, and waste water disinfection.

References

1. N. M. Lebedev. Decontamination technologies of different surfaces by means of ultrasound. Report at the international conference OJSC Concern Rosenergoatom and Energoatom “Modern methods and means of NPP equipment and spaces decontamination”. Bloyarsk NPP, Zarechny, November 14—18, 2011.

2. N. M. Lebedev, A. P. Vasiliev, M. P. Pyshnograev and others. Development and implementation of ultrasonic technologies for chemical operational cleanings and NPP fuel assemblies manufacturing. Collected works of the 5th International conference "Atomeco-2011". Moscow, October 31 — November 1, 2011.

3. N. M. Lebedev, A. P. Vasiliev, A. N. Grot, D. A. Krasilnikov. Ultrasonic technologies and equipment for intensification of technological processes while working with nuclear fuel and solid radioactive waste decontamination. Collected works of the 6th International public forum "Nuclear energy, society, safety", St. Petersburg, April 19—20, 2011.