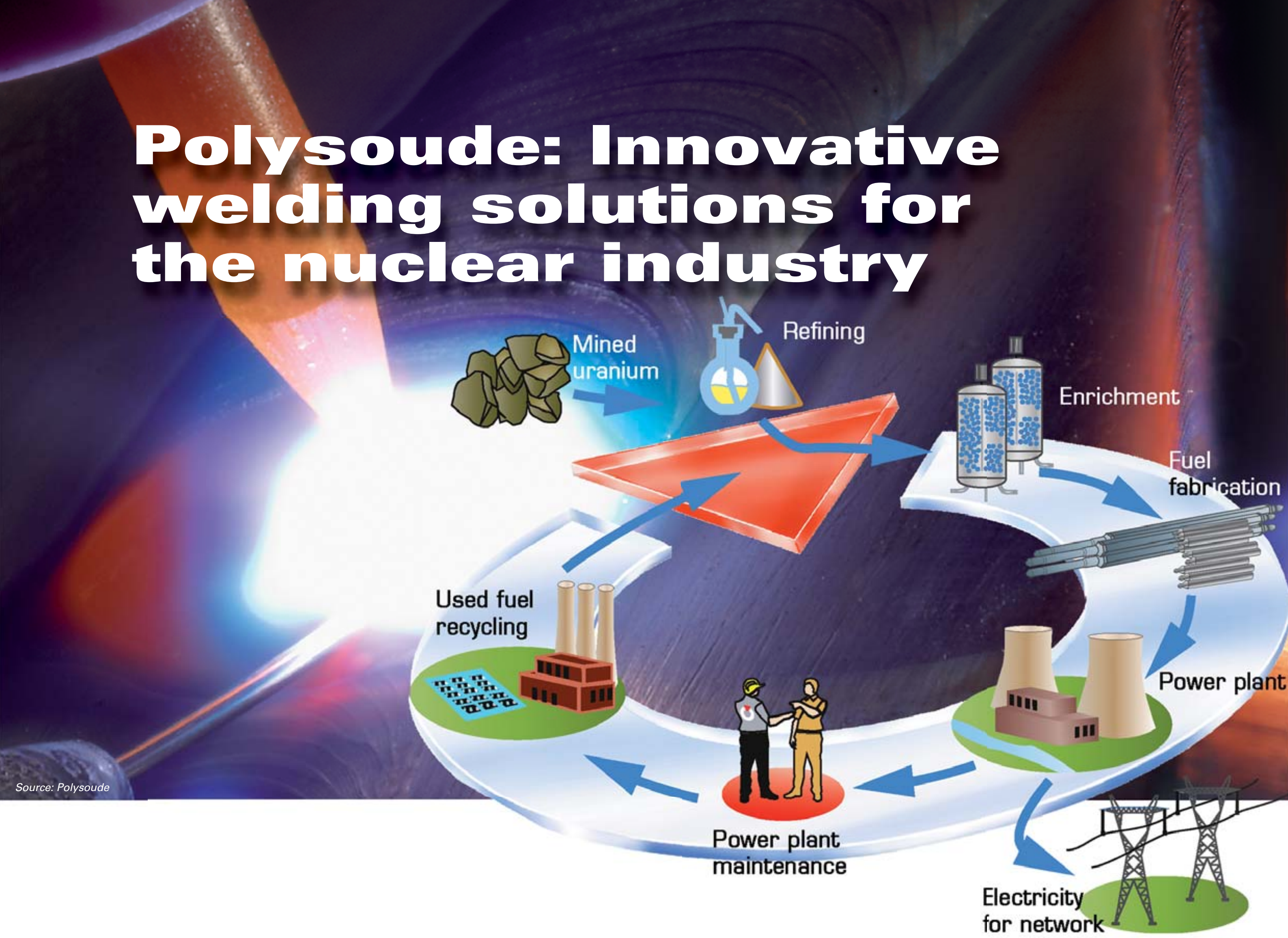
Polysoude: Innovative welding solutions for the nuclear industry



Source: Polysoude

"The design and manufacturing of welding equipment for nuclear power production is just one activity among Polysoude's wide range of applications" says Hans Peter Mariner, the group's CEO. "The company is involved from the first stage up to the very end." Experts classify the mining of uranium ore and isotope enrichment as the front end of the nuclear fuel cycle. "In fact because the heads of the rock drills used to mine uranium deposits are welded using Polysoude machines, we are actually a little bit ahead of the front end" smiles Mr. Mariner. The heavy components of the nuclear island - the reactor vessel, steam generators, pumps, and pressuriser with related primary coolant loop circuit - and components in the conventional island such as turbines and condensers are also manufactured and installed using Polysoude equipment.

By Dr.-Ing. Jürgen Krüger

Source: Polysoude

Hans Peter Mariner

"When the company was founded in 1961, TIG-welding was considered a very exotic process," Mr. Mariner recalls. "Cost-intensive equipment, the limits of joining thin-walled tubes in a single-pass-stringer-bead technique and very low productivity prevented decision-makers from getting involved. Only the outstanding weld quality and reliability achieved encouraged the first pioneers to continue."

Today, these objections have been overcome. The development of a pulsed current allows all-position welding (orbital technique) and the application of Arc Voltage Control (AVC) accompanied by torch oscillation, enables effective multi-layer welding without interruption. The improvement of power source characteristics (output power, response time, fast pulsation) results in full function sources; a successful application of alternating current (AC) with AVC achieves state-of-the-art welding of aluminium and its alloys.

The initiation of hot wire welding led to increased cost effectiveness whereas

the introduction of narrow-gap welding in conjunction with hot wire technique allows economic joining of thick-walled work pieces. Endless rotating collector welding heads allow inside and outside welding, and cladding and buttering operations can be carried out on pieces with complex geometry. Combinations of these techniques, together with video monitoring, remote control, robot-supported servicing and data acquisition on tailor-made installations, designed and manufactured by Polysoude, today operate in virtually all fields of nuclear energy production. "I must also point out our support at the back end of the nuclear fuel cycle," Mr. Mariner emphasises. "Thoroughly planned maintenance and appropriate repair of the facilities guarantee the safety of all, whereas recycling of used fuel and sustainable nuclear waste disposal are a valuable contribution to protecting our environment."

Enrichment

To achieve a controlled nuclear reaction, the concentration of the fissionable isotope U-235 must be increased to about 5%. The most common enrichment techniques are gaseous diffusion and the use of gas centrifuges. Mr. Mariner: "From a welding engineer's point of view, both methods constitute the same challenges."

Solid uranium hexafluoride (UF_6) is heated and converted to the gaseous state, then passed through a complex system of pipes and vessels, before it is condensed back into a liquid, poured into canisters and cooled to solidify. To withstand the chemically corrosive UF_6 all surfaces in contact with the gas must consist of metals such as nickel or aluminium. The installation must be totally leak-proof, and most of the piping must be installed and joined in the plant during construction, which means restricted access to the welding areas and the necessity of all-position welding. "These conditions are perfectly met by the orbital welding equipment designed and manufactured by Polysoude", explains Mr. Mariner. Mobile power sources are adapted to the harsh on-site conditions; with open MU IV orbital welding heads and low profile open carriage-type welding heads from the Polycar 30 range, thousands of high quality joints can be made automatically (Figure 1).

With the tungsten electrode connected to the negative pole of a direct current power source, and helium as protective gas, mechanised TIG-welding of aluminium and its alloys can be carried out up to wall thicknesses of 6.5 mm; thicker tubes demand a J-preparation of their ends.

"Polysoude has also implemented arc voltage control (AVC) on equipment for AC-welding of aluminium," the CEO points out. "AVC keeps the arc length stable, allowing fully automatic multi-pass welding which means greatly improved productivity."

Nuclear fuel fabrication

The final processing of UF_6 is carried out in fuel fabrication facilities where it is converted to uranium dioxide (UO_2) powder, which serves as raw material for the preparation of small pellets which are sealed into rods and bundled into fuel assemblies. The thin-walled tubes used to produce these rods usually consist of a zirconium alloy. The extremities of the tubes are sealed gas-tight by means of welded end caps.

"To set the first end cap, Polysoude has developed special high precision lathes which provide the end cap in the required position and weld it to the tube" explains Mr. Mariner. The weld is carried out without the addition of filler wire (Figure 2). The tube itself is clamped by a horizontal hollow head stock and rotates during the welding operation; the TIG torch remains fixed in the 1G (12h) position. Due to perfect control of all parameters of the TIG welding process damage to the thin tube walls or end caps can be excluded; for quality assurance purposes the equipment is often completed by a weld data acquisition and recording system.

The second end cap must be welded with the UO_2 pellets already stacked into the tube, so the environmental conditions exclude any direct intervention by the operator. To prevent the pellets from falling out, the tube is clamped in the welding unit. The TIG torch is positioned above the tube; neither the torch nor the tube rotates during the weld cycle. Controlled by a magnetic field, which is generated by a special device next to the torch, the arc is guided along the path of the welding seam on the outer edge of the tube.

After passing quality control 200-300 finished nuclear fuel rods are put into a frame and become a fuel assembly. During operation these frames and the rods are exposed to severe stress

Fig. 1. Complex piping systems in a uranium enrichment facility welded using a Polycar 30 low profile open carriage-type welding head.

Fig. 2. Precision vacuum welding lathe for high alloy steel end caps.

resulting from high pressure, elevated temperatures and strong radioactive radiation in the core of a nuclear reactor. Excellent design and workmanship are required to guarantee sufficient mechanical and geometrical stability of the construction.

Inside the nuclear power plant

The welding of heavy components in a nuclear power plant is carried out as far as possible during prefabrication using stationary welding equipment. Narrow gap welding equipment and control devices for the synchronisation of the weld cycle and the different movements are designed and manufactured by Polysoude.

The reactor vessel and the steam generators are made of forged parts with nozzles, which are called safe-ends. These must be joined to the pipes of the primary coolant circuit. As the materials of the components are different they cannot be connected easily on site.

A buttering operation on the sides of the nozzles prepares the heterogeneous joint; a deposit is welded on the side of nozzles to create a transition zone between the different metals. Buttering can be carried out during pre-fabrication in the workshop, whereas the final connection must be finished on-site with a homogenous weld between two stainless steel parts.

The inner surfaces of the reactor vessel and the steam generators are protected against the corrosive attack of the coolant by a resistant layer, the important surfaces are commonly coated in an economical manner by strip cladding. However, strip cladding is not suited for small geometries, so the inside of the nozzles and the section of the pipes with the transition zones remain inaccessible. "For this application Polysoude offers specific hot wire TIG welding heads," continues Mr. Mariner. "These collector heads can rotate endlessly and automatically follow the complex geometry at the transition between the vessel and nozzle during the cladding operation."

The manufacturing of steam generators is also carried out using Polysoude welding equipment. To achieve the demanded quality level of the tube sheet coating, the dilution rate between substrate and deposit is strictly limited. The heat input must be kept as low as possible. These are ideal prerequisites for the application of hot wire TIG welding, where heat input and dilution can be perfectly controlled and are accompanied by a high degree of repeat accuracy.

Special attention needs to be paid to the construction of the reactor vessel head; the top and bottom are complex components with numerous nozzles for control instruments and the Control Rod Drive Mechanism (CRDM). In early designs the pressure boundary welds of these nozzles were situated at the inside of the reactor vessel bottom head. In some cases, primary water stress corrosion cracking of nozzle penetrations and welds was detected and damage from local corrosion occurred, causing plant shutdowns.

Since then, sophisticated production methods have been developed to avoid such damage. To connect one of the four CDRM tubes, in the first step carbon steel is welded on the outside of the vessel head until a flat circular surface is attained. During the second step a circular cladding operation with low alloy steel wire is carried out until the specified height of the stud is reached. The inside of the stub is then drilled to the fitting diameter. The third step consists of depositing a protective layer on the inner surface of the stud by means of an internal cladding operation. During the fourth step the final connection of a stainless steel tube is prepared by a buttering operation on the side of the stud, and in the final step the heterogeneous joint is carried out as girth weld. As a result none of the welds are in contact with the coolant and all carbon steel surfaces are protected. These operations are carried out in the workshop using stationary installations, whereas the connecting pipes between the heavy components of the primary coolant loop must be assembled and welded with mobile equipment on-site (Figure 3).

In order to produce the root pass and the filling passes, low profile open carriage-type welding heads travel on pre-mounted guide rings around the stainless steel pipes. The low profile design of

Fig. 3. Safe-end flange welding.

the equipment allows the necessary radial and axial work area clearance to be substantially reduced; welding of tube to elbow joints or tube to tube joints next to obstacles like walls or the ceiling can be carried out (Figure 4).

In addition to the sophisticated features of the equipment such as automatic control of the complete weld cycle by the power source, motorised AVC and torch oscillation, hot wire welding, cost and time-saving narrow gap technique can be applied as an alternative to a conventional tube end preparation.

Many components of the conventional island are also manufactured using Polysoude welding equipment. On site, the tubes of the secondary cooling circuit have to be mounted and connected to the steam generator, the turbine and the condenser. The condenser itself is manufactured in a workshop. Manufacturing procedures and equipment are similar to those already presented for the steam generators of the primary circuit: tube-to-tube sheet welding with or without filler metal using orbital welding heads and coating of the tube sheet with mechanised cladding equipment.

The central element of modern steam turbines is the rotor with a length of up

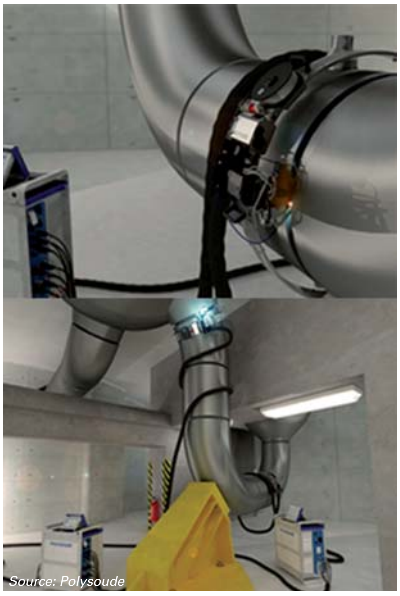


Fig. 4. Primary coolant circuit orbital NG welding.

to 20 metres and a weight of up to 350 tons. It is often assembled from two or more forged segments which can consist of different alloys. To prepare the connection, an intermediate layer is deposited on each of the upper faces of the segments, which are fixed in an upright position on a turntable. To complete the heterogeneous joint, the rotor segments are super positioned and the buttered sides are then welded together using the TIG hot wire narrow gap technique (Figure 5).

Maintenance and repair

Preventive maintenance and professional repairs are essential for the safe and sustainable operation of NPPs. The improved design of delicate constructions, e.g. connecting the CDRM tubes to the reactor vessel head, helps to avoid unscheduled downtime. Moreover, procedures and equipment have been developed and approved to provide an acceptable level of quality and safety concerning the structural integrity of such repairs. Mechanised, remotely operated welding equipment designed and configured by Polysoude allows respect of the specified procedures and helps to maintain a low dose exposure of repair personnel.

A concern of these repair procedures used to be the Bottom-Mounted Instrumentation (BMI) nozzles in the reactor vessel bottom head. In numerous cases, primary water stress corrosion cracking caused severe damage and leakage in the primary coolant circuit. In this case, the defective BMI nozzle had to be removed flush with the outside of the vessel head. As an intermediate layer, a weld pad was then deposited around the remaining hole in the vessel head, allowing creation of a reliable heterogeneous connection by welding the stainless steel replacement nozzle directly to the pad. The described procedure is known as half pipe repair. To pass control equipment, particular nozzles are mounted on the reactor vessel head. The pressure boundary of the primary coolant circuit is constituted by a seal which is called a "canopy joint". During each refuelling outage of the reactor, the canopy joints have to be disassembled; additional wear can be caused by routine maintenance. Polysoude, specialised in designing and manufacturing remotely operated orbital cladding equipment, offers a specially-developed welding machine to rebuild the joint (Figure 6).

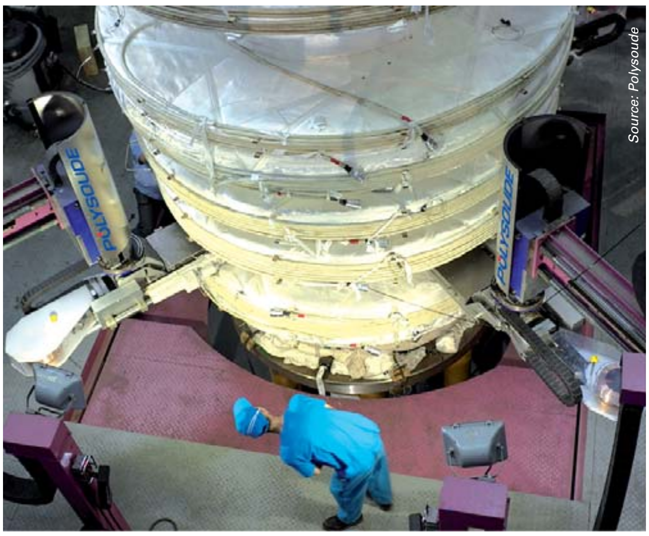


Fig. 5. TIG welding station for joining vertically super positioned rotor segments.

Recycling

In spent nuclear fuel, when it comes from a reactor, remains a considerable amount of fissionable U-235; the end of use is indeed provoked by the presence of too many neutron absorbers. France is one of the countries where spent nuclear fuel is recycled, so the transport of highly radioactive material to the recycling facilities must be ensured in a reliable manner. Polysoude is involved in the development of methods to seal the huge transport canisters lastingly using specific welding procedures. Similar problems occur when the residues from the recycling process and the other radioactive waste must be disposed. Once again Polysoude is required to offer sealing solutions which are expected to last over extremely long periods of time.

Fig. 6. Canopy joint rebuild.

Summary

"As a global player and leader in the world market with more than 50 years of experience, Polysoude proudly accepts the title "*Inventor of orbital welding technology*" Mr. Mariner concludes. "The headquarters of the company are based in the French city Nantes, with a worldwide presence in over 50 countries. Highly qualified technical, advisory, training and service personnel take part in the latest developments in nuclear power plant construction and related activities such as uranium mining and enrichment, fuel fabrication, maintenance, service and the protection of environment. Polysoude develops dedicated welding equipment for all types of applications around the nuclear energy production cycle. Last but not least", concludes Mr. Mariner, "we always pay attention to defending our position a little bit ahead of the front end".