Technical paper: Mechanized TIG welding to join rotor parts

Preheated rotor prepared for TIG root pass welding

Numerous nuclear and fossil fuel power plants are currently under construction or planned and these need to be equipped with the appropriate steam turbines. To improve cost-effectiveness and environmental protection, the efficiency of these steam turbines has continuously improved either by increasing their size and/or by raising working temperatures. Larger turbines require adequately designed rotors and equipment to produce the necessary castings, whereas production capacities for these huge parts are strictly limited. Efforts to avoid this bottleneck have stimulated a new manufacturing method.

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To avoid this bottleneck and gain increased flexibility in management and engineering, a major turbine manufacturer decided a few years ago to try a completely different manufacturing method. A batch of several large rotors had to be completed in a short time span, with no possibility of producing the requested blank forgings fast enough using conventional means: a different alternative solution had to be found. Alternative available capacities were used to forge smaller segments which would be joined together afterwards. Assembly took place in two steps: the initial joining was carried out by manual welding on vertically superimposed segments, followed by mechanized submerged arc welding as soon as sufficient stability allowed the turning of the built-up rotors into a horizontal position.

From a technological point of view, the outcome of the operation was successful and opened up the possibility to bypass limited forging capacities. However integration of this method failed due to the requirement of extensive manual welding and careful craftsmanship. A few years later the idea of producing assembled rotors arose again. Based on this previous experience, turbine manufacturers prepared a general outline of the expected features for a future production unit: assembly of two or more rotor segments with a total length of up to 12 m in vertical position. Mechanized welding offered increased performance, the highest level of weld quality, and state-of-the-art techniques (Figure 1).

Advances with new technology

Planning, development and implementation of the station was carried out in close cooperation with the French company

Figure 1. TIG welding station for joining vertically positioned rotor Parts.

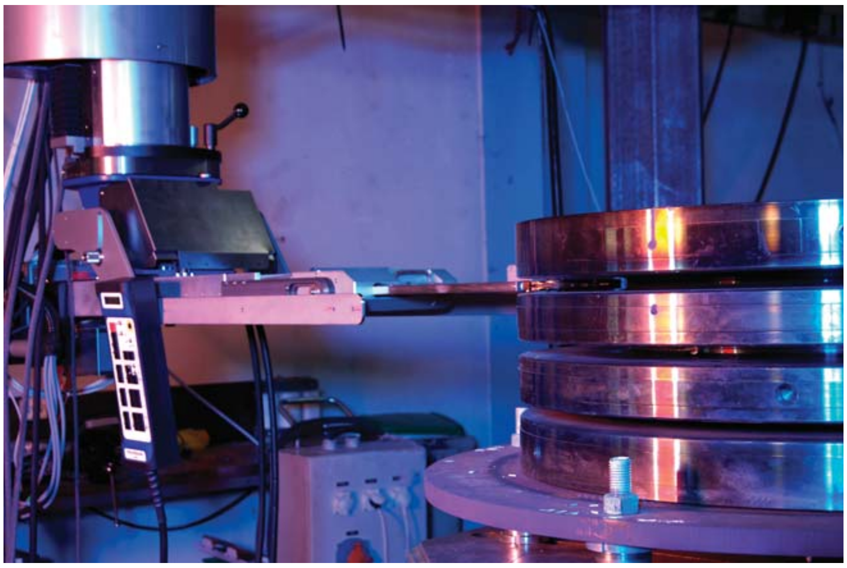

Figure 2. Horizontal arm support and installed narrow gap TIG torch.

Polysoude, a specialist in mechanized and automated TIG welding solutions. To guarantee consistently high joint quality, mechanized TIG welding was the process of choice. Here welding parameters are specified in advance and completely controlled by microprocessor-equipped devices; any programmed welding sequence can be exactly repeated as often as desired. For enhanced performance of the process "TIG - Hot Wire" welding was selected; next to the weld puddle the incoming filler wire is heated up by the additional energy of a separately supplied hot wire current.

Narrow gap preparation of the joints to be welded also leads to significant savings in arc time, filler metal and energy. Specially designed narrow gap torches became part of the desired welding tool kit. Compared to usual V, Y or U-grooves during narrow gap preparation less material has to be removed from the shaft ends and hence to be re-filled afterwards by the weld.

Numerous test welds were carried out using equipment at the Polysoude Welding Application Department in Nantes, France. Qualification of weld methods is a complex process involving Welding Procedure Specifications (WPS) with optimized weld parameters, specific gap geometry, approved filler metal, suitable energy input, precise heat management etc. Welding Performance Qualification Records (WPQR) for different base materials and material combinations need to be established (Figure 2).

Based on WPS intended for homogeneous joints of 27NiCrMoV15-6 steel, heterogeneous welds between 27NiCrMoV15-6 and 28CrMiNiV4-9 were also realized. Before the heterogeneous joint can be welded, several cladding layers have to be deposited. Therefore particular torches for this so-called buttering process also became part of the welding tool kit delivered with the equipment (Figure 3).

The shaft of an IP (Intermediate Pressure) turbine with enhanced performance is submitted to completely different operating conditions at each end. The IP-side with increased steam temperature requires high temperature creep-resistance of the material, whereas support of the large rotating blades at the exhaust section demands sufficient yield-strength of the shaft. These requirements can be realized by a rotor forged of one single material. The ends have to be exposed to different heat treatments. Unfortunately only a small number of suppliers are able to forge such huge parts. To ensure that the necessary dual heat treatment is within acceptable procuring time limits, turbine manufacturers have preferred to use

Figure 3. Buttering process for welding of buffer layers to prepare joints of homogeneous, dissimilar materials.

welded rotors as much as possible. They are therefore independent from factors beyond their control. And, not least of all, welded rotors achieve cost reductions of about 20 %.

Equipment description

The evaluation phase of the test welds was used to train a sufficient number of staff to run the future equipment. As an automatic welding process manual corrections of the process are rarely necessary. Many companies employ thoroughly trained shop-floor staff to operate similar machines. However given the expected extraordinary weld quality, and the necessary amount of experience and responsibility required, one of the major turbine manufacturers decided to draw candidates from their pool of certified manual TIG welders. The final team consisted of eight skilled experts who attended the welding school for further training on mechanized welding. During commissioning they were sent to the Polysoude facilities to practice on original equipment (Figure 4).
Meanwhile the preparations at the customer premises had advanced so far that the installation of the rotor welding equipment could be started. At the bottom, at a depth of 5 m below the ground, support and movement of the work piece can be ensured by a rotating table with a capacity of 150 t. Inbuilt collectors allow backing gas supply to protect the root pass at the inside of the rotating shaft during welding and to transmit data from several temperature sensors from the interior of the work piece to the preheating control unit.
The relocating and handling of rotor segments and entire rotors are carried out by specifically designed clamping devices and an overhead crane. A hydrostatic rotor support device on the rotating table permits precise radial and vertical adjustment of the lowest segment of the rotor to be welded. To allow precise positioning of the second segment above the already mounted first one when preheating is applied. The necessary radial gap of 1 mm occurs due to thermal expansion during preheating of the first segment up to 170 °C and disappears if the correctly mounted second segment is heated up to the same temperature. Two induction sources with a power of 350 KVA supply the energy to reach nominal shaft preheating temperatures up to 250 to 350 °C. During welding, two welders operate the system from a service platform. The service platform is suspended from two double columns to reach an optimal working position. The particular levels of the joints to be welded can be adjusted vertically, both upward and downward. The welding equipment, i.e. two power sources, video systems, cooling units etc. is placed on the service platform as well.
The welding tools are carried by two installed horizontal arm supports directly opposing one another. They can be moved up and down the columns independently of each other and from the level of the service platform. The horizontal arm supports are used to position the torches on the level of the welding gap. Each of the two horizontal arm supports are designed as an independent welding unit; torch, wire feeding device and accessories are supplied and controlled by their own welding power source and operated by one welder (Figure 5).
The remote control enables the welder to move the torch horizontally towards the work piece. Precise positioning is required as the thickness of the narrow gap torch is only 8 mm and the width of

Figure 4. One of the eight specially trained welders controls the progress of a nearly finished weld; here the conventional TIG torch is installed.

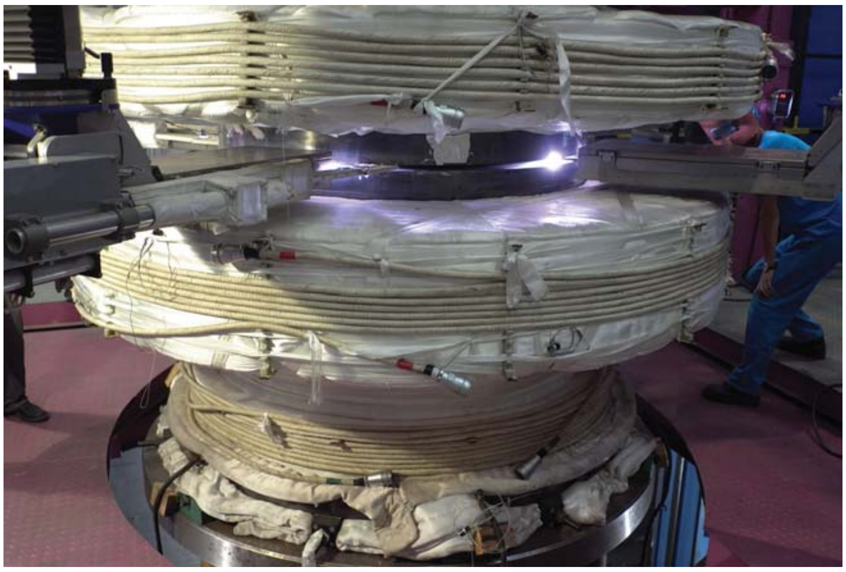

Figure 5. Welding of specimen for process qualification at the Polysoude welding application department, with two narrow gap TIG torches in opposing positions.

the gap barely exceeds this dimension. Fortunately the programmed distance to the work piece is set automatically once the electrode touches the ground of the gap, as accurate manual adjustment is difficult to implement in case of a groove depth of up to 135 mm (Figure 6).

The process

When both torches are positioned properly the weld cycles can be started. For each pass, for each diameter to be welded a corresponding program is stored in the memory of the power source. The number of programs to weld a complete joint depends on weld thickness. Typically, it represents 15 programs for the part of the weld completed by narrow gap torch and 5 programs for finishing the upper part of weld by a standard torch WP 27 (Figure 7).

For the weld of the root pass, a rotation of the work piece by 181° is programmed; both of the torches cover half of the circumference at the bottom of the gap and one additional degree for the necessary overlap at the start points of the seam. The following hot pass is then welded during a further 181° rotation of the work piece. The weld cycles for filler and cap passes are based on 540° turns of the work piece. At the end of each cycle, 3 passes are laid. Due to a uniformly programmed down-slope at the end of each cycle the welds are finished smoothly without any craters or cracks. A particular button on the remote control allows an immediate jump inside the program to the down-slope function, so the welder can end a weld cycle at any moment without danger of creating welding defects. Once the welding cycle has started, the only possibility for a welder to watch the weld puddle is by means of a video camera which is installed in the body part of each narrow gap torch. The images are shown on a monitor respectively and can distinguish arc shape, contour of the weld pool, wire arrival, and in particular side wall fusion. Although the equipment is designed to access virtually all essential welding parameters by remote control pendant, interventions of the welders are strictly limited as most of possible functions are locked by software. The most important welding parameters such as welding current, arc voltage, welding speed, wire speed are monitored and recorded independently for each torch and in relation to the angular work piece position. 100% traceability for quality assurance is granted.

The specified preheating temperature of the rotor segments of 270 °C in the welding zone is monitored by temperature sensors situated inside the rotor shaft; the results are evaluated by the controlling device of the induction sources. Data from additional temperature sensors is transferred via collectors mounted on top of the rotor directly to the service platform. The welders themselves complete a work progress protocol using mobile equipment for periodical temperature determination next to the welding zone. As preheating is interrupted during welding, the preheating temperature of the shaft decreases continuously. As mentioned, the program structure allows interrupting the TIG hot wire welding process of any torch at any moment without appearance of welding defects by activating the included down-slope function. However, as the two torches of the installation are positioned opposite each other rotation of the work piece must be maintained until the weld process of the second torch has also been ended as well by its proper down-slope. The welding speed of the torches depends on the rotational speed of the work piece and the actual diameter of the weld. This diameter increases by the thickness of each finished welded

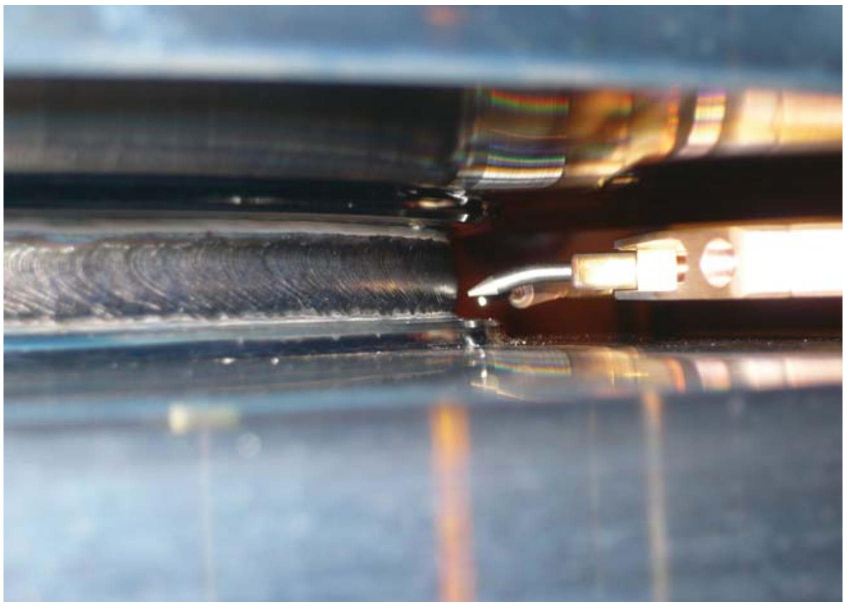

Figure 6. Narrow groove with introduced torch after root pass has been welded.

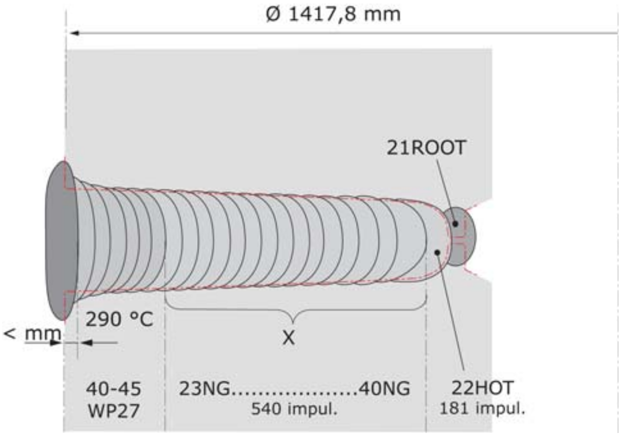

Figure 7. Disposition of welding passes. 21ROOT = root pass 180° (x 2); 22HOT = hot pass 180° (x 2); 23NG – 39NG = filler passes with narrow gap torches 540° (x 2); 40WP27 – 45WP27 = filler passes with conventional TIG torches 540° (x 2).

layer. Therefore in order to maintain a constant weld speed of the torches, the rotating table speed has to be decreased after each revolution. The necessary arc time to complete a pass varies between one hour at the beginning, should root pass welding at the small diameter next to the bottom of the gap be carried out, and one and a half hours at the final diameter of a nearly finished joint.

After each weld cycle the torches are drawn back for inspection and the cleaning of the tungsten electrodes takes place. Of course only electrodes in perfect condition are accepted for further use, if they appear degraded in any way they are discarded immediately. With the torches in proper position the weld can be continued again. The appropriate weld cycle for the pass in turn is selected by its number and started by the welder per remote control pendant.

When the welded layers arrive at a third of the final thickness of the weld, the joint becomes stable enough to allow the removal of the rotor from the equipment. In the case of rotors which are assembled of more than two segments, during the first stage of welding all joints are completed to this level. Non-destructive material testing is carried out from the interior of the hollow shaft. In the unlikely event of welding defects, the rotor is stable enough to be relocated for repair. The remaining filler passes are then completed in the same manner until two thirds of the final weld thickness have been reached. The depth of the groove now becomes so shallow that sufficient gas protection by the narrow gap torches cannot be obtained any longer. To finish the joint, the specially designed narrow gap torches are replaced by hot wire TIG machine torches.

Due to the welded zones of the rotor being subjected to final machining there are no special requirements concerning the surface of the welding seam. Since the successful completion of the first rotor, joined by recently installed equipment, full-scale utilisation in three-shift operation has been continuously ensured. Besides full satisfaction concerning weld quality and precision of the joined workpieces, there is also satisfaction with return on investment and procurement time of forged rotor parts. With the purchase of the vertical TIG welding station for rotor parts and the related developments in order to optimize materials and joining technology, customers which introduced advanced HOT TIG wire welding systems are in excellent position to catch the investment wave in newly designed, high efficiency steam turbines.