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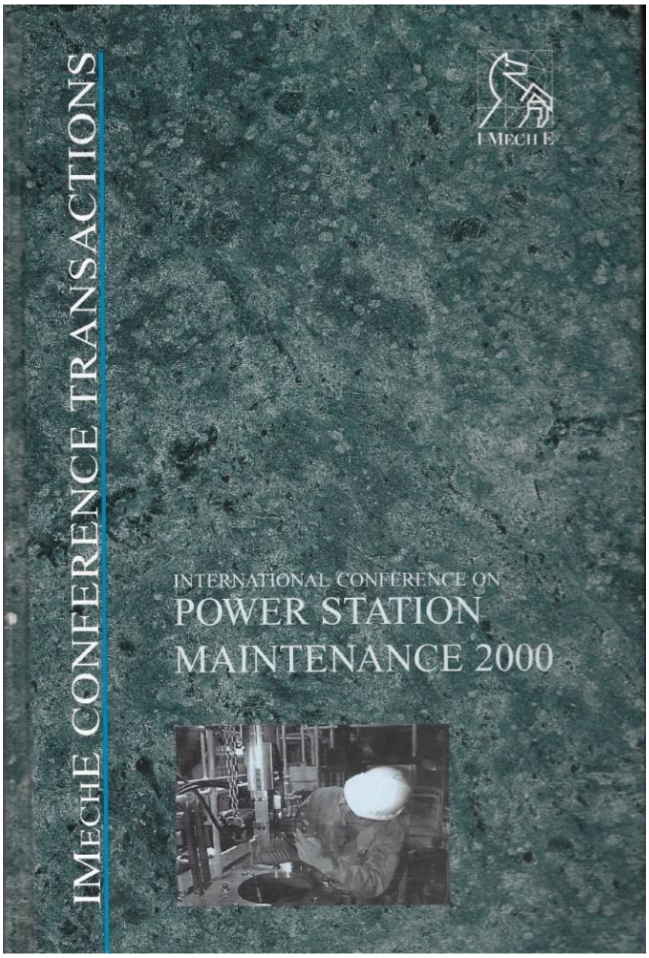

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Spiral welding — cutting the cost of maintenance, but not the quality.

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Introduction

The current economic climate places maintenance managers and engineers are under increasing pressure to reduce the cost of maintaining their plant whilst reducing down time, without jeopardising plant integrity. This pressure is set to increase for the foreseeable future. The aim of this paper is to demonstrate the spiral welding recovery and renewal solution for worn or damaged components that offers real benefits for cost savings, delivery time-scale reductions and enhanced performance compared to original engineering manufacturers (OEM) replacement spares. It will illustrate the technology involved, examine typical applications, show the benefits and advantages and explore the development of unique weld repair processes for new applications. It concludes with a case study demonstrating the repair and recovery of a Nuclear Power Station high value. long lead time component, thought to be beyond use.

The Technology

Spiral welding is a process using refined Pulsed Gas Metal Arc Welding (GMAW) technology, with skilled application coupled to automated control systems.

The Spiral Welding Process.

This is a process where a continuous weld overlay is used to rebuild worn or damaged areas, or increase the dimensions of a component part. It is a low heat input process during which individual layers of weld and their associated heat affected zones are tempered and the grain structures refined by subsequent and overlapping runs. The process requires the means to achieve continual and controllable rotation of the component being repaired. This could be a centre lathe or any other suitable means. Integrated component rotation / welding torch travel control allows a smooth homogeneous weld to be laid down on the parent material creating a surface which requires minimum finish machining.

Possible distortion of the component due to unbalanced stresses from the welding process are either eliminated or controlled to an acceptable level by the symmetrical configuration of the weld overlay and control of the heat input. Delivery of the desired repair material is via a modified and refined gas metal arc welding process. To achieve the necessary weld quality it is crucial the surface speed of the weld, heat input, wire size, gas shield and wire material are determined and delivered to close tolerances. The final weld integrity and hence the quality and longevity of the repair are dependent on these factors. The most successful spiral weld applications are those where heat input in minimised during the welding process. To achieve this, the surface speed of the weld is maximised and the wire diameter and welding current minimised to maintain a consistent weld pool. Failure to achieve these criteria may result in severe porosity of the weld and an undesirable course grain structure of the material in the heat affected zone of the weld.

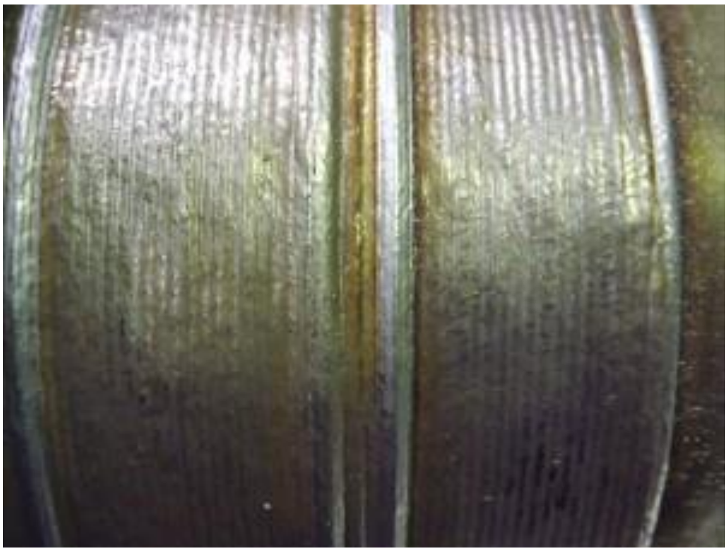

Fig 1 Close up of weld overlay

Design of the Repair and Weld Material Selection

The design of the repair should take into account the failure mode of the component, its service conditions and the possibility of preventing future failure or extending the component service life or both.

Selection of the weld overlay material is key to this.

The selection of an appropriate weld overlay material can be based on two broad criteria. Firstly, a match of the parent material with a filler wire of the same or closest available specification material.

Secondly, the use of dissimilar overlay materials to give enhanced performance against corrosion, erosion or wear. The parent material or equivalent solution generally presents few problems within the normal range of weldable materials. The design of a dissimilar overlay solution requires much greater consideration of the in service conditions of the parent component together with the suitability of the overlay material to these. Consideration must be given to the post weld grain structure within the weld and heat affected zone. Together with such factors as the difference in coefficient of thermal expansion, the strength and ductility of the two dissimilar materials and the possibility of galvanic action between the two materials and any other connected component. In order to ensure that acceptable levels of local strain are not exceeded at the interface between the overlay and substrate, either during the welding/heat treatment cycle or during service, the relative thermal expansion coefficients must be carefully considered. The criticality of this relationship increases with the in service operating temperature of the parent component. General guidelines for the difference tolerance indicate that service temperature applications below 250 degrees C can withstand up to 50% difference, whilst higher temperature matches, above 450 degrees C, should be within 10%. Strength and ductility considerations must be related to the mechanical duty of the parent component. For example, if a martensitic steel shaft with an UTS of approximately 1,000 mpa is repaired at a highly stressed location with a substantial thickness of Nickel, UTS approximately 100 mpa then the component would fail by fatigue in the repaired area. Similarly if a flexible element which might withstand service strains of up to 1% is coated with a hard-facing alloy having a fracture ductility of 0.3%, this will crack in service, and probably generate a propagating crack into the substrate. Where there is a significant difference between the electrochemical potential of the two materials there is a risk of enhanced corrosion, especially at the metallurgically sensitive area of the heat affected zone. Clearly, this must be adequately accounted for if the component will be subjected top aqueous immersion.

Pre and Post machining of the component.

Components should be fully pre-machined to remove all of the damaged area that is to be recovered. Should the damaged area include a key-way, thread, 0-ring groove or other such stress raising feature, the entire feature should be removed and reproduced completely in the replaced material. When pre machining, the tool should be designed to produce a cutting angle to assist total fusion of the overlay and parent material. Fusion defects can be minimised by close attention to the quality of the surface finish prior to welding. Due to the relatively even surface finish achieved during the welding process, post weld machining of repaired components is straightforward, even where hard-facing materials have been used.

Pre and Post Weld Heat Treatments.

The use of pre heat together with surface preparation and the use of low hydrogen, hydrogen tolerant consumable wire virtually eliminates the risk of hydrogen cracking during welding. Small components may hold their pre heat temperature during a short welding cycle due to the heat input from the welding process. Large components may not maintain the pre heat temperature in a similar manner, and will require additional heating during the weld cycle. In general, with carbon steels the pre-heat temperature used would be 225 — 250 degrees C. This temperature is maintained throughout the weld cycle. Non ferrous metals such as austenitic or duplex stainless steels or bronzes are not quite as critical, where a preheat temperature of 150 degrees C is acceptable.

PWHT is used to control the more significant problem of the transformation of the substrate to untempered martensite during welding, which significantly increases the risk of crack initiation by a wide range of mechanisms, dependant on service conditions. Detailed studies have shown that the only practical way of preventing problems in service is to reduce the susceptibility of the microstructure by fully tempering the martensite formed by a PWHT. This also relieves the residual stress in the weld. A typical procedure would include ramping up at 50 — 100 degrees C per hour to a temperature in the region of 600 degrees C or above, with the material then being allowed to soak at the upper temperature for 1 hour for each inch of the diameter of the component. This is followed by controlled cooling at 50 — 75 degrees C per hour, down to 300 degrees C and completed by normal cooling in still air.

Control of component distortion.

The welding process creates little or no distortion to the parent component, prior to PWHT, as the residual axial and hoop stresses created are generally symmetrical around the circumference of the component. PWHT, where required, will normalise these stresses. For solid or hollow component's which do not require PWHT, finish machining to the recovered areas ensures compliance with the necessary tolerances. For thin walled hollow components, allowance is made for hoop stresses causing a reduction of the bore dimension following cooling of the weld. This dimension is recovered during the finish machining process.

Non Destructive Testing (NDT)
The majority of repairs made by the process are of comparatively shallow depth and are tested using dye penetrant and magnetic particle techniques (MPI) Special attention is paid to the areas where the weld repair axially adjoins original parent material, to ensure complete fusion in these areas. Where the depth of the repair exceeds the range of MPI, ultrasonic and radiography techniques are used as appropriate.

Quality Assurance (QA).
The failure implications of repaired components can clearly be very serious for both safety and costs in repair and plant downtime. It is therefore essential that repair procedures are fully documented and the work audited for compliance to procedure. This is best achieved through adherence to an accredited ISO 9000 system.

Typical applications
The process can be applied to any component that can be rotated. Typical applications include the repair and up-grade of power plant components from: gas turbines, steam turbines (ESV, CIESV, governor valves etc) boiler feed pumps and feed regulating valves, desuperheater spray nozzles, other control valves, cooling water pumps, fans, gas circulators and many more. The cause of the original failure should be established prior to designing the recovery process such that the component can be re-engineered for increased service life and efficiency.

Fig 4. Recovery of location diameter on pre-mix nozzles.

Benefits and Advantages

As maintenance staffs are under increasing pressure to reduce costs and downtime without jeopardising plant integrity. The ability to recover, renew and often improve high value components at site or in works to short time-scales becomes a powerful tool offering a genuinely cost effective solution. Maintenance decisions can be made once the plant condition is fully known which can also allow major reductions in spares stockholdings and the associated costs. Components once considered 'scrap' can be recovered to full service at a fraction of the cost of a new component without the normal long lead time problems, or alternative costs of strategic spares holdings.

Some typical advantages would be:

- Enhanced component performance with material upgrades.
- Reduced delivery time.
- Substantial cost savings compared to OEM replacement parts.
- Alternative supplier to OEM.
- Proven technology in Nuclear, Fossil fuel and Gas Power industries.
- Reduced stock holding.

Developing unique solutions

OEM strategic parts are often seen as the preferred or only option for the replacement of damaged components. Proven spiral welding technology allows the specific development of recovery processes, as an alternative to high value replacement parts. Much experience and expertise has already been gained and proven during complex recovery processes. The development of welding applications together with special tooling and machining techniques continues to extend the cost effective recovery range of high value, long lead time component parts.

Case Study

The case study examines the repair of a 4.5 ton CO2 gas circulating rotor from the primary cooling circuit of an AGR Nuclear Power station. It explores all the aspects of the repair, from initial conception to completion, commissioning and service history to date. Initial discussions with the owner of the rotor revealed that it was unfit for service due to severe radial scoring to the bearing journal areas and gas seal face. The OEM replacement cost was in excess of £250K with a lead-time in excess of 18 months. At the request of the plant owners, a feasibility study was carried out to explore the possibility of recovering the rotor using spiral weld technology. The gas circulating rotor material was established as EN8D and an overlay material selected to match the properties of the parent component as no significant advantage could be gained by using a dissimilar overlay. A method statement and weld procedure were prepared and submitted to the client for consideration and approval by their Metallurgist and Welding Engineer. Following acceptance of these, full-scale weld tests were then carried out to prove the process and examine the resultant material properties and microstructure. A similar piece of material in specification and size as the subject rotor shaft was pre-machined for spiral welding tests of one, two and three layer overlays. Each overlay built up approximately 1.5mm of weld material. On completion, the test piece was subjected to MPI, Ultra-sonic and hardness values assessment and then cut into several segments and numerous sections taken along the deposited overlay. In some areas, notably, in the two to three layer deposits, there was evidence of carbon dilution near the fusion boundary. This had been tempered by the PWHT. Macro hardness tests were also conducted along with mechanical tests. The test piece was deemed to be a complete success with no signs of cracking at the interface. The weld substrate interface was shown to be superior to that of the substrate. Where martensite had been produced in the dilution layer, the PWHT tempered the material, removing any risk of stress corrosion cracking. As the rotor gas seal face forms part of the primary containment circuit of the reactor, a safety case, modifications procedure was prepared for approval by the Nuclear Installations Inspectorate (Nil). This approval is required before any repaired component can be put into service. Approval was obtained.

Having now established that the spiral weld recovery process was a complete success, the next stage was to carry out the repair of the actual rotor. The rotor was mounted in a lathe and the worn areas pre machined. (See fig 5 below).

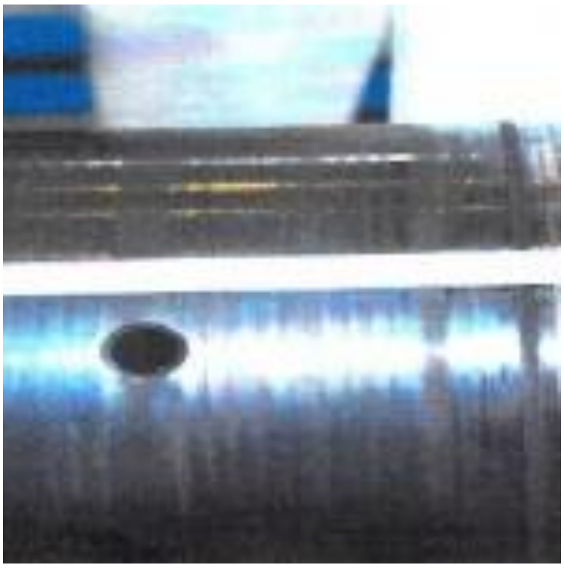

Fig 5. Damaged AGR gas circulating rotor bearing journal

Upon completion of pre machining the rotor was prepared for welding. A pre heat of 225 Degrees C was selected. Due to the dimensions and material of the rotor it was crucial that this temperature was maintained during the complete welding cycle. The rotor was wrapped in a specially designed insulated ceramic-heating jacket, with minimal access allowed for the welding torch. On completion of the weld the rotor temperature was raised to 300 degrees C and the rotor lifted into a vertical position to carry out the PWHT.

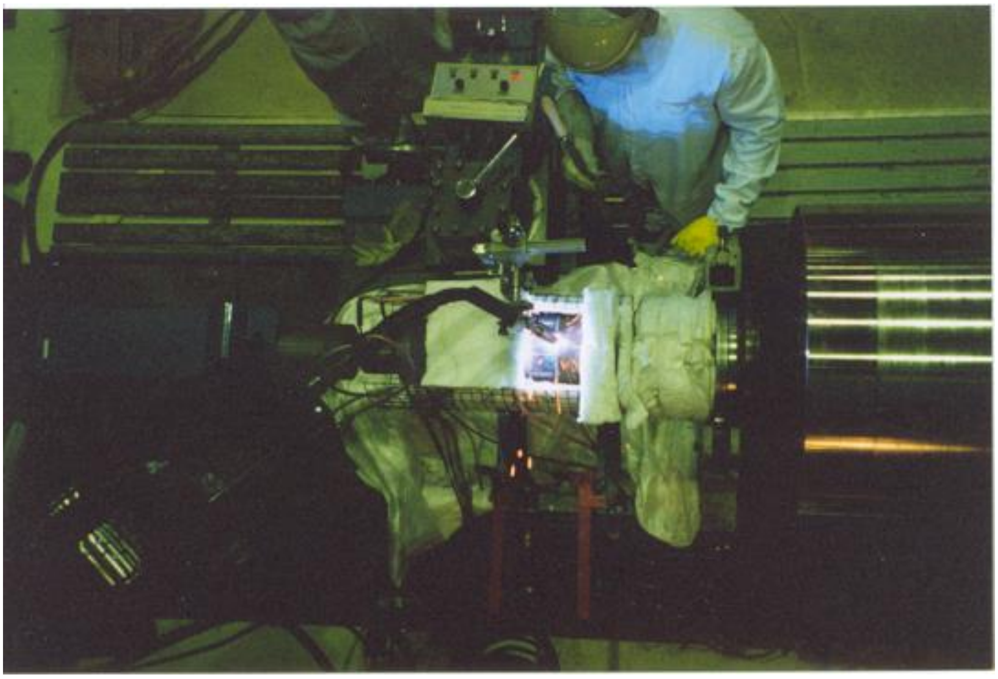

Fig 6. Rotor undergoing welding

The rotor temperature was increased at 50 degrees C per hour to a maximum temperature of 620 degrees C + or – 10 degrees. This temperature was maintained for 7 hours (1 hour per 11= diameter) The rotor cooling rate was controlled at 50 degrees C per hour down to 250 degrees C and then the thermal insulation removed for cooling to ambient. The rotor was then reset into the lathe, checked for concentricity and proof machined to + 0.020" on final dimensions to establish weld integrity by full NDT as per the original test samples.

Following the successful completion of NDT testing, the rotor was finished machined to the final dimensions, tolerances and surface finish.

This repair was carried out in 1994. The rotor was installed and commissioned back into scram under close supervision of the Power Station engineers. The reclaimed rotor has now been in service successfully for several years.

A total of four gas circulating rotors have now been recovered for two different Power stations. One of these also had a significant bend, which was removed during the recovery process.

Conclusion

Spiral Welding offers a rapid and relatively inexpensive means of recovering and the large number of rotating components scrapped each year.

Substantial cost and time savings are available and with proper control and selection of the recovered component will outlive the original and will often return substantial savings in the cost of plant operation.

The technology involved has been proven over many years with many successful operating hours for recovered components. This offers a low risk, high gain maintenance solution for plant owners and operators. Spiral welding is generally under-utilised in the Power Generation Industry. The potential savings and high probability of success should encourage maintenance decision-makers to consider the recovery rather than replacement of round section components.