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UPDATE ON REPAIR TECHNIQUES FOR LARGE EQUIPMENT

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INTRODUCTION

This report updates engineering insurance experience on several repair techniques for metal and refractory components of large equipment. In general these techniques require engineering analysis specific to each repair, reconstruction to low stress areas, proven methods, integrity verification, and operation monitoring and follow-up inspection. Several case studies are provided to exemplify the techniques.

DISCUSSION

Metallic Weld Repair

Turbine Rotor

Weld repair of damaged steam turbine rotors is gaining acceptance based on successful repairs in the past 10 years and economic considerations. There was a reluctance in the past to consider repair of turbine rotors by welding due to the special alloys required for rotors, stress concentration during operation, and thermal stress induced by welding. A poorly designed or executed repair could cause a catastrophic failure. Several large companies have now developed the expertise and proprietary methods (mostly weld materials and techniques) for weld repairs in Europe and the United States. It should be noted that welded rotors have been manufactured in Europe for over 15 years. Where feasible, these weld repairs are typically 15 to 25% of the rotor replacement cost and are completed in 8 to 12 weeks versus 12 to 16 months replacement time. Successful repairs have been demonstrated on industrial and intermediate pressure/low pressure turbine and utility low pressure turbine rotors. These repairs are now used both to repair rotors that sustained an operating failure and to extend rotor useful life.

Most of industrial and utility steam turbines operating today were installed prior to 1965. These units were typically designed for 30 years service. Rotors manufactured prior to 1958 require special evaluation because of inferior alloy purity and homogeneity. Stress corrosion and thermal fatigue are common to industrial grade turbines in later stages of useful life. Repairs to utility steam turbine rotors are more complex than industrial units especially if the components are operating above 800°F. Thermal fatigue, creep, and embrittlement are commonly found in these units.

Basically a combination of three welding processes are used: submerged-arc, narrow-gap, or tungsten inert gas (TIG). Low stress areas are selected for weld repair. The repair generally consists of the following steps:

1. Evaluation and feasibility study to determine if a weld repair can meet operating specifications.
2. Disassembly, cleaning, and inspection.
3. Critical measurements and engineering.
4. Machining of the weld repair area.
5. Non destructive examination.
6. Weld area preparation and preheating.
7. Repair with welding.
8. Post weld anneal.
9. Non destructive examination and mechanical tests.
10. Finishing and dimensional checks.
11. Operational tests.
12. Operational monitoring and shutdown inspections.

Successful repairs now in Europe and the United States have shown that weld repair is a viable alternative to rotor replacement and retirement.

Case Study 1

A severe crack was found in the 9th stage of intermediate pressure/low pressure rotor during a 1986 shutdown inspection of a 175 Mw utility steam generator at the Los Angeles Department of Water and Power (USA). After careful analysis, the rotor was severed and a new 9th through 12th stage stub was welded to the original rotor. Complete testing was conducted on the repaired rotor and discarded section to assure compatibility. Vibration monitoring systems were installed and periodic inspection conducted. The unit has operated satisfactorily to date. The repair cost $600,000 (US) versus replacement at $3,500,000 (US).

PWR Generator Tubes

Sleeve welding has now gained acceptance for corrosion related problems in pressurized-water-reactor (PWR) tubes since 1975. Plugging was the common, inexpensive repair for tube leaks, but resulted in plant derating after 5 to 10% of the tubes were plugged.

A typical nuclear PWR plant has two to four steam generators, each containing 3500 to 15,000 tubes varying from 5/8 in. to 7/8 in. diameter. Sleeve welding is now performed by remote controlled, robotic equipment to minimize radiation exposure to the technicians. The process involves cleaning the tube, sleeve installation, sleeve expansion, upper sleeve weld, lower sleeve weld, and non destructive examination. The sleeve material is thermally treated Alloy 690 fabricated from tubing specified to ASME code case N-20. The United States Nuclear Regulatory Commission and Swedish nuclear regulatory authorities have licensed the repair at numerous facilities.

Repairs are successful 95 to 99% of the time. Advantages of sleeve-weld repair are low cost, absolute leak tightness, pressure integrity, automated reliability, minimal radiation exposure to personnel, low residual stresses, test verification, ability to plug, and corrosion resistance.

Mechanically installed sleeves are actually leak reducing and less effective. Brazed sleeve installation has been much less reliable. Nickel plating only reduces corrosion and is limited to low stress areas.

Case Study 2

During shutdown in 1985, 128 tubes were sleeved welded by a remote automated system in 10 days on a 1090 Mw PWR generator in Illinois (USA). Accepted repairs were 122 (99%) and the unit has been in service to date.

Large Equipment On-Site Repair

Worldwide there are a number of very large equipment assemblies that were literally assembled and/or fabricated on-site, such as civil work projects, mining, heavy metal fabrication, chemical and utility plants. In some cases, equipment and component replacement in the event of failure is uneconomical without literally razing and rebuilding the plant or precluded due to configuration, rigging and/or transportation requirements. Welding repairs which were previously limited to the equipment manufacturer's site are now possible due to portable preheat and postheat capabilities. Complexity increases with the size of equipment, design loads, age, and lack of design information.

Case Study 3

During an operating inspection of a 50,000 ton hydraulic press, a complete vertical crack was found in the middle of a 36 ft. 6 in. long by 14 ft. high by 10 in. thick web of a lower crosshead beam. The crossbeam weighed 110 tons. The press was fabricated from A-36 steel and installed between 1952 and 1955 with the plant literally built around the press. The special railroad which had been constructed to transport large components of the press had been taken out and the only economical option was to perform the repair on-site. A plan was developed to remove the cross beam, perform a qualified weld repair with preheat and postheat, and reinstall the crossbeam on site. It took four weeks to develop a plan, six weeks to remove the crossbeam, seven weeks to repair, and six weeks to reinstall. The property damage was $2,200,000 (US) and the Extra Expense was $1,100,000 (US).

Stress Relief For Fatigue Cracks

The traditional approach for abating fatigue cracks has been to drill holes in the crack tips to reduce stress concentration by increasing the radius of curvature. New techniques have been developed for cracks initiating at the ends of a longitudinal weld with the crack tip in a region of the plane away from the weld. These techniques have also been applied to cracks situated at the toe of a transverse weld. The two methods essentially induce compressive residual circumferential stress around the hole by expanding it radially.

Technique 1 involves drilling and reaming a hole at each end of the crack, then inserting an interference fit bolts. The bolt is frozen for installation.

Technique 2 also involves drilling and reaming, then inserting a split sleeve which is cold expanded. Both techniques retard fatigue cracking significantly better than simply drilling holes in the crack tips. Furthermore, experience with Technique 1 is generally better than Technique 2. Effectiveness decreases with crack length in all methods.

LLPS Coatings

Low pressure plasma spray (LLPS) coatings have proven excellent, cost effective wear resistance for rollers in hot strip mills. The rollers are placed in a vacuum chamber and a proprietary plasma spray is applied. The technique has three advantages: negligible change in material composition, high tensile strength, and high bonding strength. The steel industry has tried other methods such as hard facing with electroplating, arc welding, and thermal spray coating. Generally, these methods are not hard enough, change composition, or do not bond well to the rollers.

Case Study 4

Nippion Steel reports roller life increased at least 100 times with LLPS treated rollers. Manufacturing costs are approximately seven times conventional treatment processes.

Cold Mechanical Repairs

Cold mechanical repair is a process for the repair of cracked or broken castings, forgings, or fabricated sections generally of cast iron or steel. The process utilizes a series of locking components applied under ambient temperature conditions (in the absence of heat). These components take many forms, locks, laces, master locks, key locks, angle locks, etc. The selection of metals used for various locks is made on the basis of maintaining a lower coefficient of thermal expansion than the parent metal. The effects of corrosion are minimized by using material of proper galvanic range.

The art of cold mechanical repair dates back to the industrial revolution for repairs of large structural castings. However, only within the last 10 to 15 years have several firms applied engineering principles to the technique. Typical equipment candidates are steam turbine casings, large machine frames, hydro-turbine runners and casings, forges, fly wheels, excavating equipment, etc. Cold mechanical repair techniques should not be used as a substitute for weld repairs where required such as pressure vessels. The process involves:

1. Determination of suitable application.
2. Inspection and evaluation.
3. Repair design to restore original component strength.
4. Repair by spanning the crack with higher strength repair material, anchoring it into the stronger, less stressed area of parent material.

Case Study 5

During disassembly of a 1936 110 Mw compound steam turbine generator in 1984 some 90 fatigue cracks were found requiring repair 13 inches in the uppercase exterior, 124 inches in the uppercase interior, 41 inches in the lower case exterior, and 215 inches in the lower case interior. The turbine was unique, vertical piggy back, one of three remaining in the Unites States and five world wide. The shells could not be economically replaced nor the units replaced with modern design due to space limitations in the power house. An outside specialist firm was retained and the unit restored with cold mechanical repair and returned to name plate service after six months.

Refractory Repair

Ceramic welding is now accepted as the state-of-the-art process for making durable repairs to refractories in glass furnaces at operational temperatures and with minimal interruption to production., The technique was developed in the 1970's by Glaverbal for repairing glass tanks. Previously, repairs required shutdown of the furnace, rebricking or application of a monolith patch. It was first used commercially for the repair of coke ovens and is now used throughout Europe and the United States for repairs to glass furnaces. The process consists of projecting a dry mixture of refractory particles and metallic powders in a stream of oxygen onto the hot face of the refractory zone to be restored. An exothermic reaction occurs between the metal powders at about 2200 degrees Centigrade. The refractory powder is raised to its melting point and bonds to the repair zone substrate. The materials are selected to have the same chemical and physical properties of the original refractory. The repair is carried out without the need to cool down the furnace. Superior results have been achieved over previous methods and in less time.

Case Study 6

A European glass manufacturer's operating furnace exhibited severe refractory erosion in 1988 endangering the structural integrity of bracing steelwork. Critical areas were the joints between the crown and back wall, crown and wing walls, and the float line. The Fosbel ceramic welding process was used and successfully completed over several weeks.