Innovative IGT Repair Solutions to Enhance Power Plant Profitability

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The Challenge

Between 1995 and 2001, more than 200 gigawatts, of mostly F-class gas turbine combined cycle power production, was initiated in the United States alone. This phenomenon was driven primarily by independent power producers (IPPs) and their merchant market strategy for selling power.

This historic "bubble" of capacity was followed by a "bust" period between 2001 and 2005, where little or no new power was created and the surplus was absorbed into the marketplace. In many parts of the U.S., excess capacity drove down market prices for electricity, financially impacting many IPPs. At the same time, the price of natural gas tripled, resulting in significantly higher electricity prices. Power companies passed-through these higher fuel costs to retail consumers, leading to a public and governmental outcry for a return to strict price regulation.

Due to this new norm in natural gas prices, electrical power producers are heavily scrutinizing every aspect of their plant operation expenses. Some of the greatest potential for cost efficiencies is being found in the operational lifecycle of F-class gas turbines. This renewed and reinvigorated look at controlling operations and maintenance costs has prompted innovative market solutions. In fact, several new F-class hot gas path turbine parts suppliers and improved repair technologies for these components have been introduced to the industry in recent years.

The first stage nozzle is proving to be an integral factor in controlling the costs associated with refurbishing and repairing F-class hot gas path parts during routine maintenance. Qualified repair companies and power plant owners regularly must assess the cost-benefit scenario of scrapping or repairing these critical parts. The repair method used for first stage nozzle trailing edges is particularly important because of material erosion caused by thermal fatigue, oxidation and foreign object damage.

Procuring entire new replacement nozzle segments is not usually a viable option due to the high cost of the cobalt, nickel-based investment castings and because of demanding, quick cycle maintenance schedules. To address these challenges some non-OEM suppliers have developed proprietary processes to design and manufacture first stage nozzle trailing edge "coupons" for use by qualified repair shops. The coupons exactly match the geometric dimensions and metallurgical properties of the existing part and include pre-machined cooling air holes so they can be simply assembled into the existing nozzle segment. This innovative technology introduces a new viable solution to service facilities and plant operators who are weighing the pros and cons of repair or replacement.

These coupons are currently being used by the repair industry and have been field-validated on practically the entire B&E class of General Electric gas turbines.

This "set it and forget it" coupon provides a fast, robust and cost-effective repair option. It also significantly increases the lifespan of the original component compared to a typical hand weld repair (if a simple weld repair can even be performed).

SLS of 7FA First Stage Nozzle Trailing Edge Replacement Coupon

Today, first stage nozzle trailing edge coupons for GE's 7FA+e gas turbine are in demand and are ready to be implemented in service shops.

This article outlines the market need for this new type of repair technology, its inherent advantages over the typical refurbishment methods, and an overview of the basic design and development process of manufacturing a trailing edge replacement coupon.

The Opportunity

Hot gas path components of large, industrial gas turbines used for power generation are typically designed to operate between 24,000 to 36,000 hours (3 to 5 years) before they require refurbishment. During the initial repair cycle, it is not uncommon to observe some cracking in the trailing edges of the first stage nozzle. In cases like this, a low-tech weld repair process would be acceptable. However, welding is a manual process and the fillers used are not as metallurgically-sound as the base metal. Therefore welding these cracks is not a long-term repair solution; it is more of a band-aid or stop-gap approach.

During the second repair cycle, extensive cracking and burning-away of the trailing edge base metal is common. This is called oxidation. At this point, the part requires a more holistic repair approach. Foreign object damage (FOD), such as failing combustion system components that are liberated downstream, can cause even more extensive distress or oxidation. A decade ago, this part would have landed on a scrap heap. However, in today's economy and with the exorbitant cost of replacement parts, this is a perfect candidate for a trailing edge coupon repair.

The Process

First stage nozzle trailing edge replacement coupons are strategically designed and manufactured to be an exact dimensional and metallurgical match to OEM first stage nozzles. Using a new or refurbished OEM part, the surfaces of the nozzle rails, platforms and airfoils are laser or optically scanned and the data is imported into an industry standard CAD/CAM software package. Because nozzle airfoils are hollow to allow air to cool the part during operation, Computer Tomography (CT) scans, X-rays or cut-ups of the original part are used to determine the wall thickness and internal geometry features. Surface features, such as cooling air exit holes, are also measured. With this information, Stereolithography (SLA) or Selective Laser Sintering (SLS) is used to generate the prototype (Figure 1) to serve as a visual tool and as a way to initiate casting.

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The casting process is as important as the coupon's design. Therefore factors that could affect the coupon's dimensional and quality requirements are addressed before casting begins. These issues include tooling design, gating methods, shrink factor, microporosity and grain size limits and surface imperfections.

The coupon is then cast in metal, using an industry standard nickel, cobalt-based superalloy called FR FSX-414. Coupons are cast with similar-sized material grain structure, the same as the base nozzle material.

The Value

At this point, the coupon is ready to be machined. It is this stage of the manufacturing process that sets coupon suppliers apart and provides the service shop and power plant operator with the prospect of a high value, predictable repair method.

The first stage nozzle is hollow and allows internally delivered cooling air through a series of holes or slots that cover the outside of the airfoil during operation. This air provides a boundary layer on the nozzle surface which prevents the nozzle material from melting under the extreme heat of the combustor-supplied gas, which can reach temperatures up to 3,000 degrees Fahrenheit.

Additionally, some first stage nozzle designs also use thermal barrier coating (TBC), a yttria stabilized zirconia material, to further insulate the nozzle material from hot gas. Surface cooling is achieved through a system of intricate trailing edge slots and rows of shaped cooling holes on both the pressure and suction sides of the nozzle airfoil.

The coupon becomes a valuable and robust process to service shops when the intricate cooling hole geometry is already machined into the coupon itself. The holes are made using an Electro-Discharge Machining (EDM) process that creates a highly accurate shaped hole geometry. EDM, in its simplest form, is machining using an electrical spark. A controlled electrical spark is used to erode away material that can conduct electricity. A series of controlled electrical discharges takes place between the two conductors separated from each other by a film of non-conducting liquid, called a dielectric or deionized water. When the electrode is plunged into the base metal, a hole is created. It is a highly specialized process which requires competencies in EDM tooling and equipment design, as well as electrode plunging methodologies.

With the coupon ready to be installed, the damaged nozzle segment is prepped for repair. Figure 2 shows a trailing edge replacement coupon being readied for welding on a GE Frame 6 nozzle. When coupons are manufactured with precision EDM cooling hole geometry, the repair process is significantly simplified and much more effective.

Previous techniques have been tried where the coupon is welded in place first, and the cooling features are added later. This approach can often result in scrapping the entire coupon due to the mismatching of the cooling holes. With the stringent quality requirements demanded by GE F-class gas turbine operators, especially cooling flow specifications, a "best effort" repair process is unacceptable.

The Solution

Some coupon manufacturers sell first stage trailing edge coupons in both partial and complete sets, depending on the requirements of the service shop and the level of repair needed for GE Frame 3, 5, 6B, 7E and 9E gas turbines. The GE Frame 7FA+e coupon is currently available to qualified service shops and can be delivered in as little as four weeks. As firing temperatures of gas turbines continue to increase, coupon manufacturers will likely introduce coupons for second stage nozzles as well.

As demand for power increases, so will the number of gas turbines. Thus, power plant owners will rely more heavily on replacement coupon technology to control operational costs associated with repairing their growing legion of turbines. Not only will repaired parts last longer with coupons than the typical weld repair due to more consistent metallurgical properties, the investment casting coupons offer more precise dimensional control and the value-add of pre-machined EDM cooling holes.

Like any product, not all are equal. Manufacturing reliable first stage nozzle trailing edge replacement coupons requires extensive knowledge of the power generation industry, experience casting high-quality superalloys and expertise in EDM drilling for the demanding specifications of the aerospace and industrial gas turbine markets. Only coupon manufacturers that can honestly make these claims will offer the industry a viable alternative to traditional welds in first stage nozzle refurbishments.