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87-GT-66

Gas Turbine Components Determining Repairability and Innovations to Refurbish Parts

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INTRODUCTION

This paper deals with the repairability of hot gas path (turbine section), combustion, and compressor section (cold end) components in large (non-aeroderivative) industrial and utility gas turbines (4500 to 100,000KW). We will discuss; USA demographics, overhaul cycle recommendations, types of damage and part deterioration, more complete inspections repairability based on alloys and applications, and innovations for refurbishment.

GAS TURBINE DEMOGRAPHICS IN THE USA

The major manufacturers of the 4500 to 100,000KW utility/industrial size non-aeroderivative gas turbines sold and installed in the USA are General Electric and Westinghouse. Table 1 illustrates the estimated population distribution and other comparisons.

Table 1 Gas Turbine Populations - USA (estimated)

Mfg.'s	Models	No. Units	Total
General Electric	FR3000 (1st Unit-1949)	300	
	FR5000 (1st Unit-1957)	850	
	FR7000 (1st Unit-1970)	250	1,400
Westinghouse	W21-101 (1st Unit-1949)	100	
	W171 &191 (1st Unit-1959)	150	
	W251 (1st Unit-1967)	120	
	W501 (1st Unit-1968)	200	570
Others			30
TOTAL			2,000

Table 1 Notes

Note 1	Utility Owners	60%	Note 2	G.E.;hot end-driver	
	Industrial	15%		West.;cold end-driver	
	Pipeline/Transpt.	25%			
Note 3	Simple Cycle	86%	Note 4	Natural Gas	45%
	Regen. Cycle	12%		Oil	30%
	Combined Cycle	2%		Dual Fuel	25%

MAINTENANCE/OVERHAUL CYCLES

Manufacturers have made many recommendations based on unit size, fuel, operating conditions, etc. for maintenance intervals. The three types of gas turbine inspection/overhauls are; Combustion, Hot Gas Path, and Major. Many owners have found over the last 30 years, that the extent of the deterioration and damage may change; from year-to-year, similar units in different service, from model-to-model, and even sometimes in identical units operating side-by-side. Figure 1 is a simplified nomenclature diagram to correlate different manufacturer's names for the same components.

The most frequent maintenance inspection is in the Combustion section, and consists of fuel nozzles, cross-fire tubes, combustor baskets and transition pieces. Less frequently performed, is the Hot Gas Path inspection, which includes the components in the combustor section, plus the Turbine section rotating blading, stationary vanes/nozzles, shroud blocks, etc. Far less frequently performed is a Major inspection which requires a complete dissassembly of the unit at the horizontal split line, removal of the rotor and an inspection of the compressor components as well as the combustion and turbine section parts. Table 2 contains a homogenization of recommendations for inspection/overhaul cycles for continuous and cycling duty gas turbines.

Presented at the Gas Turbine Conference and Exhibition, Anaheim, California — May 31-June 4, 1987

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Figure 1 Gas Turbine Nomenclature

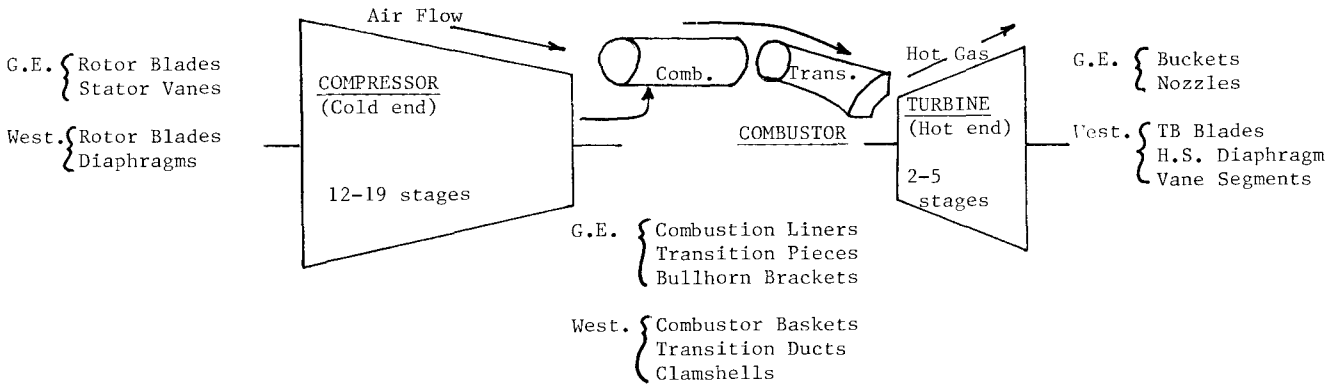


Table 2 Inspection Interval Recommendations

Type of Insp.	Continuous Oper. 1000-8760 hrs/yr.	Cycling Opr. <1000 hrs/yr.
COMBUSTION	6mos.-1 year 2500-8000 hrs.	1 - 2 years 1000-2000 hrs.
HOT GAS PATH	2 - 3 years 4000-20,000 hrs.	3 - 5 years 2500-5000 hrs.
MAJOR	5 years 15,000-40,000 hrs.	7-10 years 5000-10,000 hrs.

TYPES OF DAMAGE/DETERIORATION

Generally, the damage and deterioration that effects the combustor, turbine and compressor sections can be divided into three types:

Type 1 External Damage caused by foreign object damage (F.O.D.), fretting, corrosion, erosion, and thermal cracking from low cycle fatigue.

Type 2 Internal Structural Damage such as gamma prime grain coarsening, unwanted sigma phase formation, carbide precipitation along the grain boundries and minor creep.

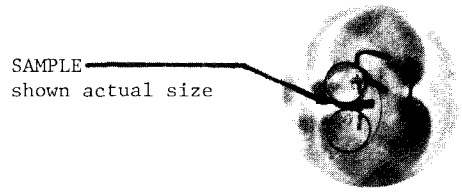
Type 3 Unrepairable Damage, high cycle fatigue in rotating parts, major creep in certain alloys, and penetration of dangerous elements such as copper, silver, lead, etc. into the surface of the part. Also, major external damage that negatively effects the physical and design capabilites of a part.

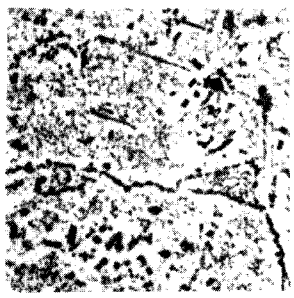
Most gas turbine component damage will be type 1 and/or type 2.

External damage can generally be detected visually, through NDE-liquid penetrant, and by good dimensional integrity checks. This damage can usually be repaired by blending, welding, brazing and the usual forms of mechanical repair. Most of these parts can be repaired for 10-40% of the cost of new in 1-3 weeks.

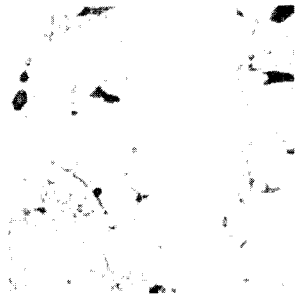
Internal structural deterioration can only be detected by removing a very small sample of the blade/vane, usually from the trailing edge in an area that is readily blendable. This sample is then mounted, polished, etched and photomicrographed at 200 to 1000 times magnification, and analyzed by someone experienced in super alloy metallurgy. This type of deterioration can usually be corrected with rejuvenating heat treatments. In the past many parts were put back into service just because they looked good externally, but without a metallographic examination, you can't know the internal condition of the material or even if it is in the proper condition to be weld repaired.

Figure 2 Sample and Photomicrographs





500X BEFORE H.T.
blocky carbides along grain boundries



500X AFTER H.T.
annealed and weldable

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REPAIRABILITY & REFURBISHMENT

Turbine Section

The basic design of the gas turbine has remained unchanged for over 30 years. However, with the increase in firing and operating temperatures in each new model or modification, the super alloy blade/vane materials have changed (see Table 3). Only 25 years ago, the turbine inlet temperatures were around 1400°F (760°C), the new models now are operating at 2000°F (1090°C), a 40% increase.

Table 3 Gas Turbine Materials (partial list)

	General Electric	Westinghouse
TURBINE SECTION	Nozzles-300SS,X-40, X-45,N-155, FSX-414 Buckets-300SS,400SS, A-286,M-252, U-500,U-700, In-738, Waspaloy, GTD-111	Diaph.&Vane Seg. - 300SS,N-155,U-500,X-40,X-45,M-509,ECY-768 Blades-U500,U-520 In-700,In-X750,U-510 U-720
COMBUSTION SECTION	300SS, Hastelloy X, L-605, In-X750,N-273	300SS, Hast. X, RA-330, In-617
COMPRESSOR SECTION	403SS,422SS,450SS, 300SS	403,410,450SS, 300SS

Because there are over 25 different blade/vane materials used in just the turbine section, it is extremely important to know exactly what is the material composition of the component to be repaired.

(1) Cobalt base super alloys are used in the hot section because of their good resistance to hot corrosion and are generally used along with some stainless steels for stationary components such as; nozzles, vane segments and diaphragms.

(2) Nickel base super alloys are used in hot section rotating buckets and blades because of their superior strength at high temperatures.

Repairs to different material groups require different; pre-weld heat treatments, pre-heats during welding, controlled atmosphere welding, filler rod materials, welding techniques and procedures, post weld heat treatments, and NDE techniques. (See Table 4)

Before 1975, repairs to hot section components were limited to blending only. Usually these parts were replaced after 25,000 to 40,000 operating hours, based on OEM recommendations. With metallographic knowledge of the condition of the base material, almost all stationary components and many rotating components can be rejuvenated and repaired with proper heat treatments, special welding techniques, super-alloy overlays (brazing), and hot isostatic pressing (HIPing). Because of pre-repair heat treat requirements and possible weld contamination, all parts requiring these major repairs should first have any coatings or surface contaminations stripped chemically or mechanically. The high temperatures that super alloys must be annealed at would diffuse any surface coating remnants further into

Table 4 Material Groups - Gas Turbine Components

300 Series Stainless	Wrought Chromium - Nickel Austenitic; 304,309,310,316,322,347	a) Not hardenable by heat treat. b) Can be welded without pre or post heat treatment, except if sigma formation is present.
400 Series Stainless	Wrought Martensitic Chromium; 403, 410, 422	a) Usually requires warming during weld repair. b) Requires post-weld heat treat.
Iron Base	1) Wrought, solid-solution; N-155, RA-330 2) Precipitation - hardened; A-286	a) Pre-weld heat treatment. b) Weld low heat input technique to prevent cracking.
Cobalt Base	Cast, solid-solution; X-40, L-605, HS-188, X-45, FSX-414, HS-25, ECY-768,M-509	a) Usually requires annealing before weld repair. b) Welding with proper filler rod and low heat input technique. c) Post repair age-hardening to restore strength.
Nickel Base	1) Wrought, solid-solution; Hastelloy X, RA-333,In-635, M-252, U-500,U-520, U-700, Waspaloy, In-750, N-263 2) Cast; U-500, In-738, GTD-111, U-710, &-720, Hastelloy X	a) Usually needs pre repair anneal. b) May require weld repair in a controlled atmosphere chamber. c) Post repair solutioning and age hardening for cast alloys.

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the base material than desirable, and possibly reduce the alloy strength and melting point. A little coating .002-.005 inches (.05-.13mm) at the surface is known to be beneficial, but if the coating alloy Al, is diffused too far below the surface it could be harmful.

Cobalt base super alloys should only be welded when the material is in a solution annealed condition, which can be determined from hardness checks and metallography. If the material is not in this condition, then an annealing heat treatment of 1900-2300°F (1035-1260°C) in vacuum is required. The exact temperatures and time are determined by the metallurgical condition and material composition of the component. It is also important to use weld filler rod that matches the composition of the base material or is very close. During welding, shrink cracking near the weld can be prevented by using low heat input/special weld techniques. Depending on the condition and composition of the part, a post weld anneal maybe necessary. Age hardening heat treatment, done at lower temperature levels than annealing can increase the tensile strength, erosion, and impact resistance of the part. Some age hardening can take place during operation of the turbine.

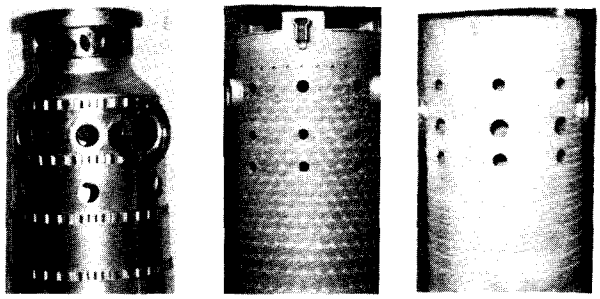
Nickel base alloys will require an anneal heat treatment to make the material more workable before repair. Welding a nickel base alloy should be done in a controlled atmosphere chamber (argon or argon-hydrogen mixture) to significantly reduce weld contamination and micro-cracking. Weld filler rod must be carefully chosen for each of the different alloys, because the filler rod will be more ductile than the base material, but have much less creep strength. In high gamma-prime nickel base alloys such as In-738, micro-cracks in the heat affected zones near the weld cannot be avoided, however, the base material even with micro-cracking has better creep strength than the filler rod material. The limited creep strength of the weld filler material is the reason for weld repairs being done only on the upper part of the airfoils and in root sealing areas on rotating blades where there are less centrifugal stresses. The following are rotating blade area weld repair considerations; (1) stress levels, (2) temperature levels, (3) wall thickness (weldability decreases as wall thickness increases), and (4) base material composition. Creep life minimum is approximately in the middle of the blade. HIPing cannot cure cracks open to the surface. As you can see, there are many more concerns about turbine section blade repairs than the stationary parts.

Combustion Section

As indicated in Table 3, there are only a few materials to be concerned with, and with proper understanding these parts can be easily repaired. This is, however, the hotest section of the gas turbine with temperatures exceeding 2300°F (1260°C) and the major components are made of sheet and thin walled cross sections. Major temperature gradients increase thermal degradation of these components.

Combustion liners or baskets are the carburetor and combustion chamber of the gas turbine, where air and fuel are mixed and ignited. There are three basic manufacturers designs for combustion liners: Westinghouse- wiggle strip and cooling port construction, General Electric louvered one piece cylinder, and GE slot cooled (series of holes) one piece cylinder (See Figure 3).

Figure 3 Typical Combustor Designs

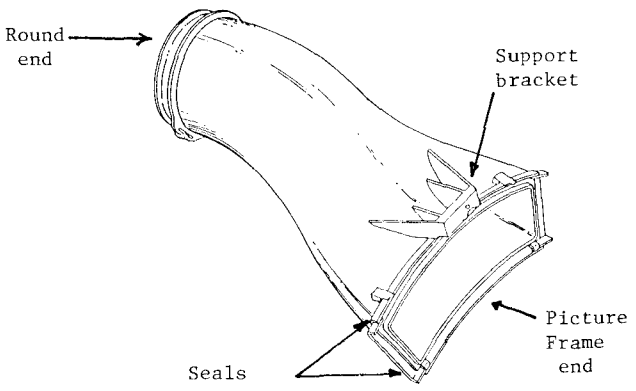


Westinghouse Wiggle-Strip | G.E. Louver | G.E. Slot-Cooled

Westinghouse design combustor cans can have major body sections, spring seals and domes inexpensively replaced because they use a spot welded, stacked assembly. It is very important, however, to calibrate spot welding parameters to obtain void free welds that also achieve good tensile strength tests. Proper cylinder stacking heights, concentricity, fuel nozzle flange runout, and cross fire flange alignment are very critical. G.E. designs have similar dimensional repair requirements, but, because the main body cylinder is one piece, repairs are limited to minor defects, or small section patch replacements. Newer design units use internal thermal barrier coatings.

Transition pieces or ducts are special high temperature pipes that direct the combustor's hot gases to the first stage stationary nozzles/vanes. They are round on the end that attaches directly or indirectly to the combustion liners and trapezoidal (picture frame) on the nozzle end. Although more rugged in material thickness and design than the combustors, they also suffer thermal cycling and fatigue, so an annealing heat treatment before repair can be very beneficial. Mounting bracket, round mouth and picture frame end repairs, and picture frame seal repairs or replacements are the most common repairs. Because of the shape of transitions, checking in a fixture, and restoring dimensions is a key factor in repair. Newer designs use thermal barrier coatings and anti wear coatings in areas most vulnerable to fretting.

Figure 4 Transition Piece/Duct



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Compressor Section

Generally speaking this is the most maintenance free section of the gas turbine. Blading and vane materials are usually 403 or 410SS, and see temperatures ambient to 600°F (315°C). The gas turbine consumes over 60% of it's output just to drive it's own axial compressor. Compressor fouling and cleaning are normally the biggest maintenance factors, but some utility and industrial users have units operating in hostile enviroments that also introduce corrosive and erosive elements. The majority of compressor blade/vane damage seen by the author has been from FOD caused by; ice on the inlets, sheared off stator vanes or rotor blades that failed in high cycle fatigue and went downstream, flashlights and bolts left in the inlet during overhaul, and other internal mechanisms including improper variable inlet guide vane and bleed valve operation, and surface pitting attack.

Compressor stationary components generally have low stress levels and most stator vane and compressor diaphragms with corrosion, erosion and FOD damage can be economically and effectively repaired. Pre-weld warming in excess of 450°F (230°C) is recommended for welding 400SS and a post weld stress relief to minimize cracking in the heat affected zone (HAZE). As in all components, particular care should be taken to measure and restore the dimensional integrity of all parts.

Compressor rotor blading requires the same metallurgical and dimensional requirements for repair as the stationary parts but, because of centrifugal loading, the areas to be repaired must be evaluated using similar factors to hot section blading; stress levels in the area to be repaired, effect on chord width, and cross-sectional thickness. Properly welded and heat treated, the repaired area is only 70-80% as strong as the original forged material. Because of these stress factors, weld repairs on compressor rotor blades are generally limited to the upper half of the airfoil and careful blending (no sharp edges or corners) is the only recommended repair to the lower half of the blade. A good rule of thumb is that blading should be replaced when the loss of cross-sectional area exceeds 10%.

Properly repaired rotor and stator parts can restore compressor output to new condition, as evidenced by operating results over the last six years from approximately 60 major refurbishments. There is no known metallurgical failure of the nearly 20,000 rotor blades and 60,000 stator vanes that have been weld refurbished.

INNOVATIONS

Rejuvenating Heat Treatments

As long as the base material has not sustained unrepairable internal structural damage, all super alloys can be restored to as new condition. With proper metallurgical evaluation; a special soak time, higher/lower temperature, different heat-up or cool-down rate, or even a different gaseous enviroment (hydrogen, vacuum, etc.), variations of normal heat treatment cycles can provide the needed stimulus to metallurgically restore base material grain structure to as new condition.

Vane Coupon-Insert Repairs

Even though dimensional and internal structural damage may appear fatal to some stationary parts, premanufactured and custom made coupons or inserts can mechanically replace these damaged areas. Frequently, internal structural damage isn't always uniform throughout the entire vane airfoil. Many premanufactured coupon inserts already have cooling holes, strengthening ribs, etc., and are readily available and inexpensive.

Combustion Section Parts of Components

Burner can body sections, domes, cooling parts, spring or hula seals, crossfire collars and flanges, fuel nozzle flanges etc., are available for most common combustion liner designs and models. Some of these parts are even interchangeable from model-to-model. Transitions are a different problem because usually only the picture frame seals are replaceable. However, brackets, body sections, etc. are now being replaced with new material, successfully.

Compressor Section

As previously discussed many rotating blades and almost all stator vanes can be metallurgically, dimensionally and economically repaired. Most individual blades and vanes can be weld repaired and reheat treated for less than 25% replacement cost. On the diaphragm design compressor stators, air seals can be replaced with newer design innovations that prevent future fatigue failure and damage.

Super-Alloy Overlays

These materials are no longer just high temperature brazes, they now contain powdered filler metal compatible with the base material. Overlaying is a very useful technique for repairing FOD, corrosion, erosion and low cycle fatigue cracking in hot section components. Proper cleaning of the parts, a clean enviroment for overlay material application and an immediate high temperature cure in a vacuum furnace at 10^{-5} Torr, are necessary because of the reactiveness of the super alloys to oxygen. Pure braze can be used on cracks about .004-.012 in (0.1-0.3mm). Wide-gap brazes, which contain filler metal can repair defects and surface build-ups to .39 in (1mm). However, total build-up of material on a blade surface should be limited to 30% of wall thickness. Properly composed and applied super alloy overlays; (1) will not spall off, (2) can be weld or braze repaired later, (3) are compatible with base materials with respect to coating, heat treating, creep and corrosion resistance.

CONCLUSIONS

Gas turbine components do not always have to be replaced with new because they reach a certain cronological age (operating hours and starts) or externally appear damaged. Proper dimensional examinations and professional metallurgical analysis are critical for component and material condition evaluations. Innovative heat treatments, mechanical weld repairs, coupon-inserts, overlay (brazes), and other repair/refurbishment procedures are; technically sound, experience proven, and cost effective methods for gas turbine component life extension.

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ACKNOWLEDGEMENTS

The author wishes to recognize:

Tom van Schaik-Pres., Elbar B.V.-Netherlands
Giel Marijnissen-Mgr., R & D, Elbar B.V.

and special thanks to

Hans van Esch - Metallurgist, Hickham-Elbar

for their efforts in reviewing the technical content of this paper.

REFERENCES

1. T. van Schaik, "Hot Component Repairs Reduce Gas Turbine Operating Costs", Modern Power Systems, April 1983, pp29-35.

2. J.S. Dodgson, "Repair Techniques for Hot Gas Path Components in Industrial Gas Turbines", ASME paper 82-GT-104.

3. G. Marijnissen, "Repair of Gas Turbine Components" will be presented at the CMAC Conference, Warsaw, Poland, June 1987.

4. C.T. Sims & W.C. Hagel, The Superalloys, New York, 1972, Chapter 5, Cobalt-Base Alloys.

5. M.H. Haafkens & JHG Mattheij, "Weldibility of Nickel-Base... Superalloys", Welding Journal, November 1982.

6. JHG Mattheij, "Role of Brazing in Repair of Superalloys..." Materials and Science Technology, August 1985, Vol. 1.

7. H. van Esch & G. Marijnissen, "Braze Repair Techniques", Turbomachinery International, September 1986, pp 29-32.

8. G.W. Scheper, AJ Mayoral, and EJ Hipp, "Maintaining Gas Turbine Compressors for High Efficientcy", Power Engineering, August 1978, pp 54-57.

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