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Remanufacture of Jet Engine Compressor Components

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A description of the various mechanical operations employed in the remanufacture of gas turbine engine compressor components such as blading, rotor disks and spacer, vane shroud assemblies and air seals are given. The operations described include tungsten inert gas, plasma needle arc and electron beam welding, furnace and torch brazing, glass bead and shot peening, magnetic particle and ultrasonic inspection, plasma spray and diffusion coating. Emphasis is given to the effect of these operations on the mechanical integrity of the engine component. For example, the effect of welding, brazing, peening and diffusion coating on the high cycle fatigue strength of compressor stator and rotor components is discussed. The effect of repair operations on jet engine compressor performance is also considered.

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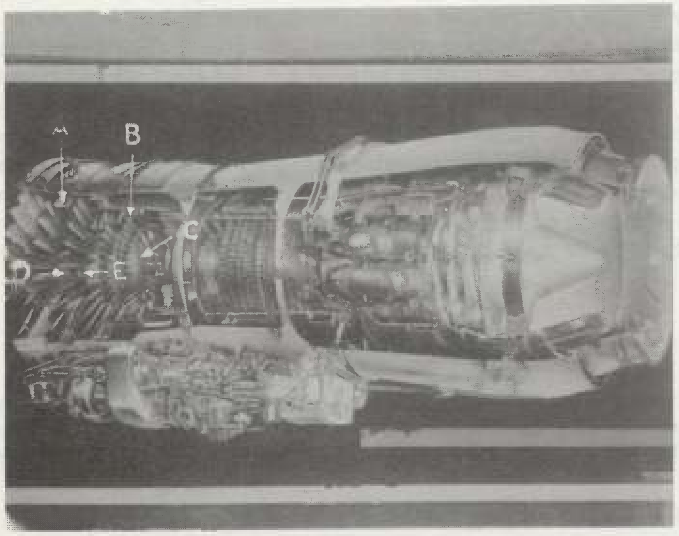
INTRODUCTION

The excellent performance of the gas turbine engine in commercial and military aviation is a matter of record. It is questionable whether the extent of commercial air travel presently taken for granted could have been possible without the economy, reliability, and quality built into the older Pratt & Whitney JT3D, JT4D, and JT8D engines, as well as the new up-dated JT8D, JT9D and General Electric CF6 engines. During the early days of the jet engine in commercial aviation, there were significant doubts as to whether these complex and expensive systems could ever be maintained and operated economically. Military operation had shown the improved performance and excellent reliability of jet engines, but the systems economics remained in question. After a short period of time, however, through inventive approaches in maintenance, such as new diagnostic techniques as well as new repair and component modifications (mainly coatings and air cooling techniques), the economic benefits of the jet engine has been demonstrated. In this paper, a discussion will be given of the repair approach to a number of the major components of the gas turbine engine compressor.

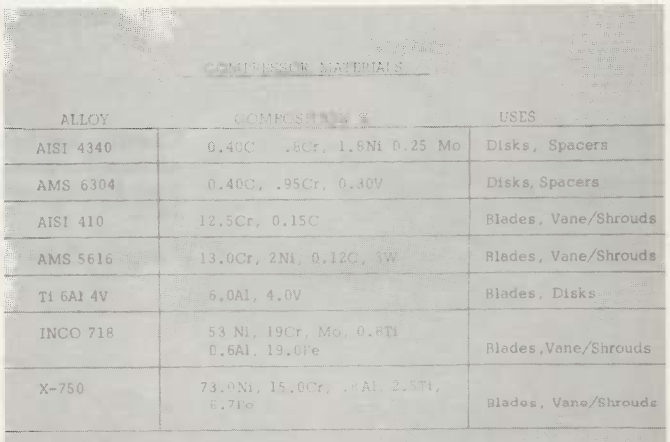


(a) Stator vanes
(b) Blades
(c) Disks
(d) Air seals
(e) Rotor spacers

Fig. 1 Sectional view of jet engine showing major components

Fig. 1 is a schematic diagram of a jet engine pointing out the placement of the blading, disks, rotor spacers, stator vanes, and air seals that make up the jet engine compressor. A description of specific repair operations on these components will be given in the following sections. However, before getting into this discussion, it is worthwhile outlining the major materials utilized in conventional gas turbine engine compressor components. Table 1 is a summary of the base metals used in compressors. Rather than going over the more detailed metallurgical reasons for the specific use of each material, a short generalized description of each material, enough to aid

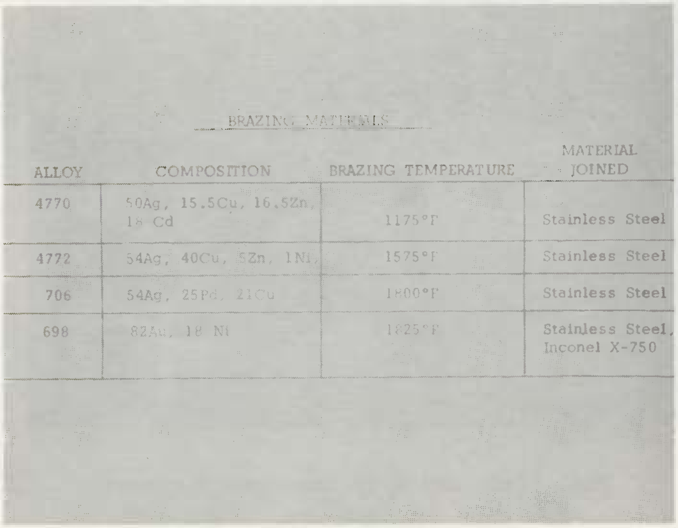
Table 1 Base Materials Used in Compressor Components



COMPRESSOR MATERIALS

ALLOY	COMPOSITION %	USES
AISI 4340	0.40C .8Cr, 1.8Ni 0.25 Mo	Disks, Spacers
AMS 6304	0.40C, .95Cr, 0.30V	Disks, Spacers
AISI 410	12.5Cr, 0.15C	Blades, Vane/Shrouds
AMS 5616	13.0Cr, 2Ni, 0.12C, 3W	Blades, Vane/Shrouds
Ti 6Al 4V	6.0Al, 4.0V	Blades, Disks
INCO 718	53 Ni, 19Cr, Mo, 0.8Ti 0.6Al, 19.0Fe	Blades,Vane/Shrouds
X-750	73.0Ni, 15.0Cr, .8Al, 2.5Ti, 6.7Fe	Blades, Vane/Shrouds

Table 2 Brazing Alloys in Brazing Compressor Components



BRAZING MATERIALS

ALLOY	COMPOSITION	BRAZING TEMPERATURE	MATERIAL JOINED
4770	50Ag, 15.5Cu, 16.5Zn, 18 Cd	1175°F	Stainless Steel
4772	54Ag, 40Cu, 5Zn, 1Ni	1575°F	Stainless Steel
706	54Ag, 25Pd, 21Cu	1800°F	Stainless Steel
698	82Au, 18 Ni	1825°F	Stainless Steel, Inconel X-750

in the evaluation of the repair schemes, will be given.

Disks and Spacers

AMS 4340 and AMS 6304 are the most often used materials for compressor disks and spacers. These are used normally in the forged condition. The use of very high strength, low alloy steels is necessary since these components are very highly stressed, particularly at aircraft takeoff and landing. Disks are, therefore, also low cycle fatigue limited. In most Pratt & Whitney engines, these components have a finite life; after a specific number of cycles, they are scrapped. These low alloy steels are also very susceptible to aqueous corrosion; therefore, they always require protective coatings. Since these materials materially lose their strength above 800 F in new compressors, nickel base alloy disk (Inco 718) is often used in the hotter portion of the compressor. Titanium alloy disks (Ti-6Al-4V) are also used in the cooler front end of the compressor when engine weight is an especially critical design requirement

Blades, Vanes, and Shrouds

AMS 5616 and its counterpart, "Greek Ascoloy," is the workhorse material of jet engine blading and vanes. This material is a "410 type" stainless steel possessing excellent high-temperature fatigue strength, along with reasonable processing costs. Where higher temperatures, above 900 F are experienced, nickel-based alloys, such as Inco 718 and Inconel X-750, are utilized. These materials, although not susceptible to aqueous corrosion as AMS 5616, are extremely expensive to fabricate, are difficult to repair weld, must be brazed utilizing expensive gold based braze alloy under hard vacuum, and cannot be inspected by the high resolution fluorescent magnetic particle technique.

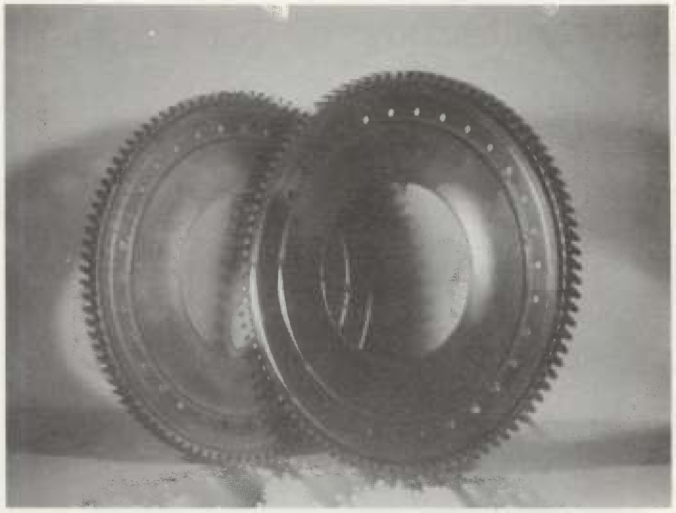


Fig. 2 Compressor disk without blading

Titanium alloys (mainly Ti-6Al-4V) have seen extensive use in fan blades because of their excellent strength to weight ratio.

Joining

Welding of "410" type stainless-steel stationary non-airfoil components, such as shrouds and cases, is accomplished using AMS 5776 (410 base) welding rod and the Tungsten Inert Gas welding technique. No repair welding, other than electron beam welding of Ti-6Al-4V fan blades, is allowed on any rotating component or stationary airfoil component. Applicable brazing alloys are shown in Table 2. AMS 4770 braze is only used in the low-temperature section of the compressor, and AMS 4772 is utilized with AMS 5616 stainless where slightly more severe environments and loading are encountered. Ag-Cu-Pd and Au-Ni braze is utilized in conjunction with Inconel X-750; therefore, it is almost always vacuum brazed.

SPECIFIC REPAIR PROCEDURES

Disks

Fig. 2 is a typical Pratt & Whitney disk. Very few repairs are allowable on this component because of the high stresses experienced during takeoff and loading. As indicated previously, disks are designed for low cycle fatigue failure. Therefore, no structural change such as may be found in weld heat-affected regions are allowable.

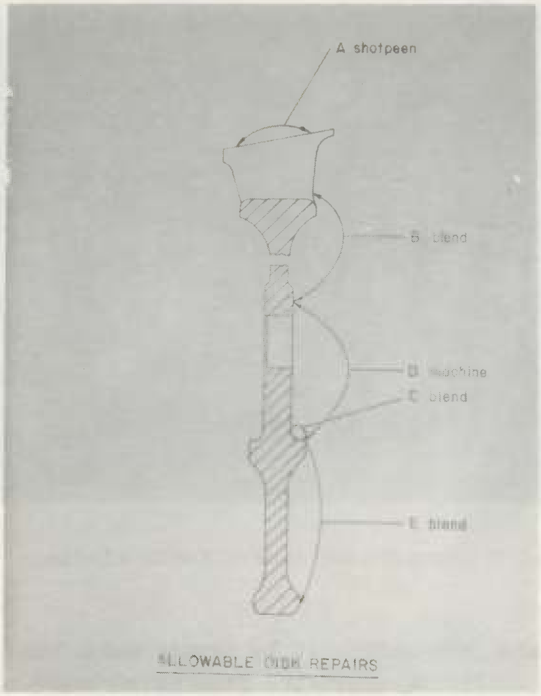


Fig. 3 Extent of rework repairs which can be performed upon disks

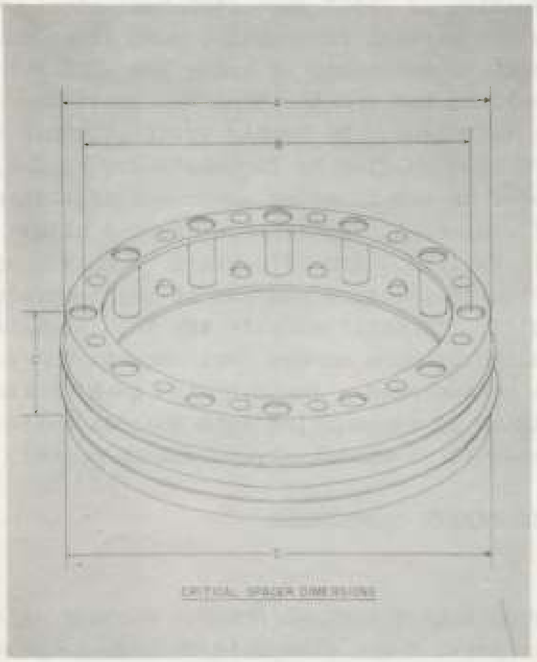


Fig. 4 View of compressor spacer with tie-rod sleeves removed. Letter denotes critical dimensions

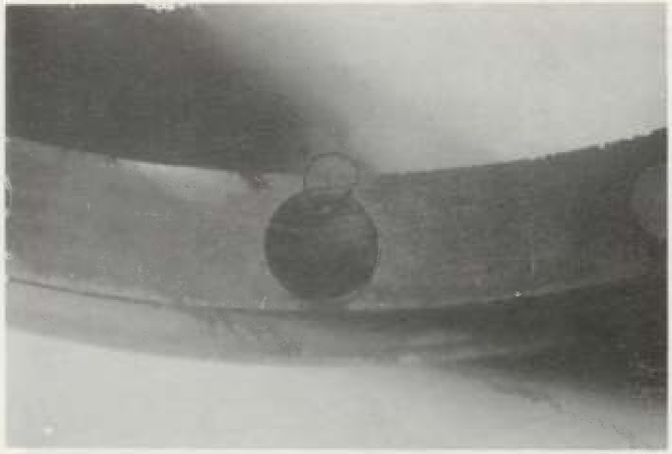


Fig. 5(a) Crack in compressor spacer

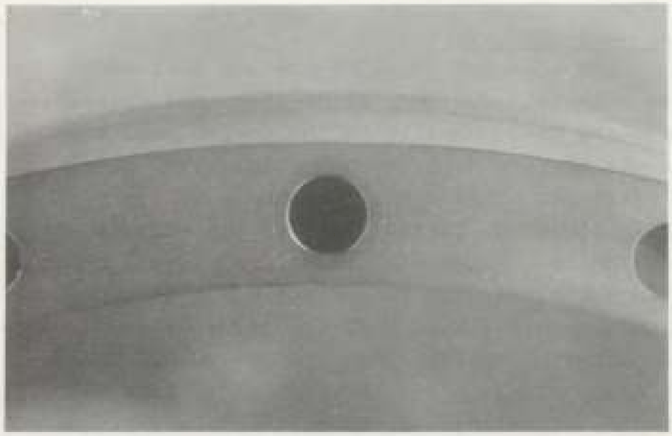


Fig. 5(b) Crack repaired and sleeve installed in compressor spacer

No welding, brazing, or other thermal treatments are, therefore, carried out on disk components. Minor blending is allowed as shown in Fig. 3. This blending must be carried out by abrasive stones or ultra-high-speed grinding wheels whereby heat generated is minimal. In order to insure that even this minor blending does not effect fatigue strength, a high intensity shot peening is often carried out on blended areas. The highest stressed are experienced in the dovetail slot area, A. This area is heavily shot peened to an intensity of 12A to insure against a fatigue strength reduction due to machining scratches, corrosion pitting, or other surface defects. To

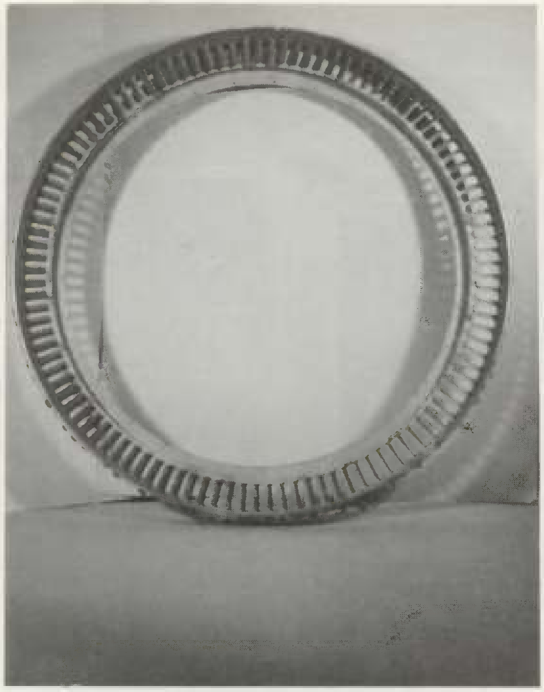


Fig. 6 Stator vane assembly

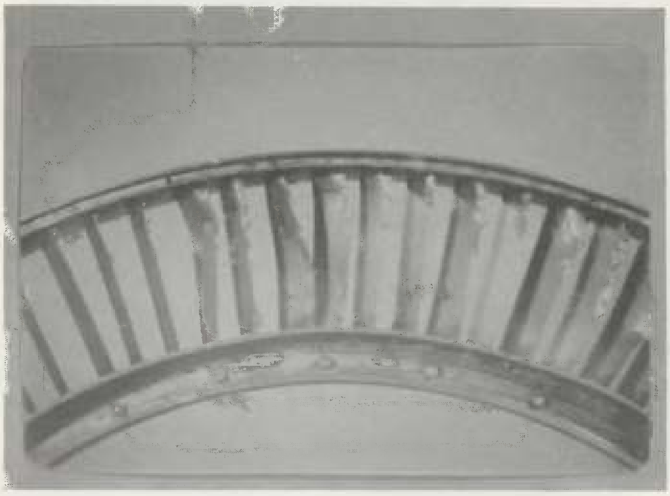


Fig. 7 Damaged stator vane assembly. Vanes must be replaced

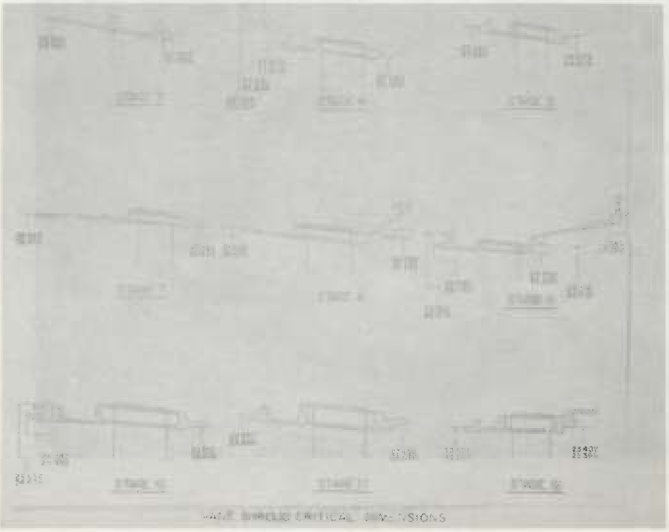


Fig. 8 Dimensional limits which must be maintained in repair of stator vane assemblies

maintain fir between the compressor spacer and disk, specific snap (fit) diameters may be sulfamate nickel plated and machined. In many compressor repairs, the grind-plate (sulfamate Ni) grind technique is used to repair worn or distorted components. The sulfamate-Ni process is utilized so as to insure against hydrogen evolution and possible hydrogen embrittlement of these fatigue sensitive components.

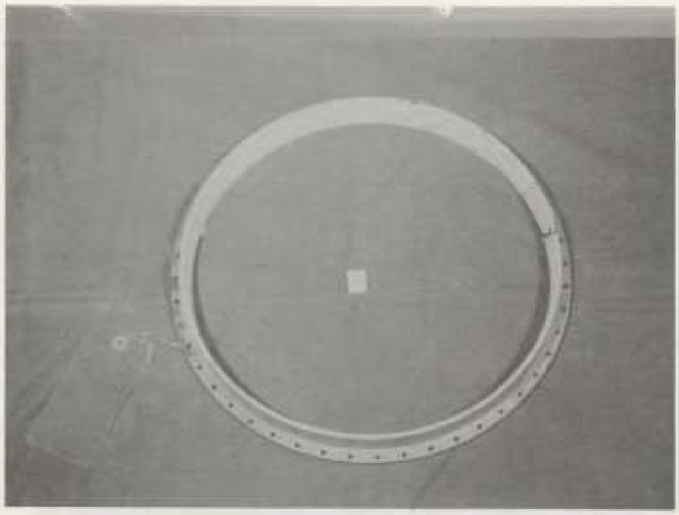
To protect these low alloy steel components from aqueous corrosion, nickel-cadmium plating is often used. Standard practice includes the deposition of approximately 0.0005 in. sulfamate nickel and 0.0003 in. cadmium.

Spacers

Fig. 4 is a schematic of a typical Pratt & Whitney JT8D rotor spacer. This spacer contains integral knife-edge air seals. Although much research has been carried out on the repair of these knife-edge seals by electron beam, TIG or plasma needle arc welding, as of yet no extensive repair has been found to be reliable. One weld repair has been found to be acceptable. This repair is the so-called tiebolt hole repair. Fig. 5(a) shows a typical tiebolt hole crack, and Fig. 5(b) indicates the weld bead repair. After repair, all diameters must be maintained at ±0.001 in. and concentricity to within ±0.0005 in. This maintenance of dimensions is only possible by extreme control of weld and stress relief fixtures as well as careful use of Ni-buildup and machining. To prevent distortion in a flexible part of this type, plasma needle arc welding is often employed. This technique, utilizing a narrow collimated arc, provides for closer control of heat input. Again, AMS 6304 spacers must be NiCad plated to protect against corrosion.

Blading

Compressor blading is designed for high cycle fatique. It, therefore, must be carefully maintained and repaired in order to eliminate any possible surface defects, such as foreign



(Air Seal)

(In Assembly)

Fig. 9 Inner air seal for stator vane assembly after repair and installed in assembly

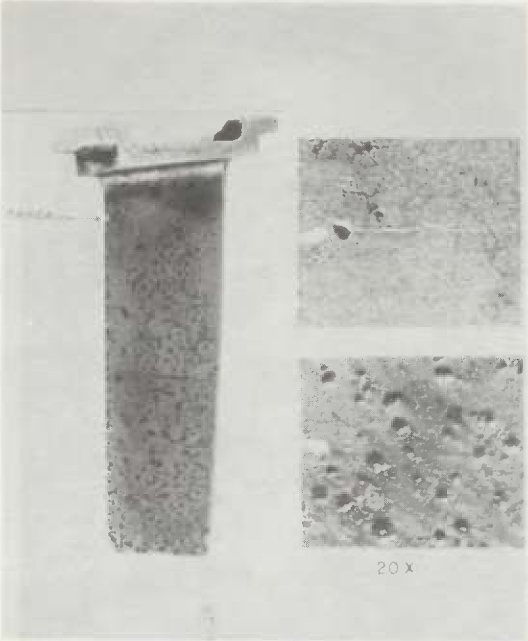


Fig. 10 Fatigue crack initiated at corrosion pit on stator blade

object damage, machining scratches, or corrosion pits. No welding on steel compressor blading is allowable. One weld repair has been approved. On JT3D, JT8D, and JT9D Ti-6Al-4V fan blades, electron beam welding of leading edge inserts is allowed. This repair has produced extensive savings of these very expensive components.

Blending is allowed on both the leading and trailing edge to a predetermined extent.

The depths of airfoil and blade root pitting are also carefully controlled. Wherever possible, fluorescent magnetic particle inspection is employed since this produces approximately a 5 times improvement in crack resolution. To improve the fatigue strength of these blades, automatic shot peening is extensively employed. Blade roots are peened to an intensity of 10 to 12Å and airfoils to 8Å wherever possible. Coating of blading with diffused aluminide (Chromalloy A12) or NiCad plating is also employed. A detailed discussion of this subject will be given in the next section.

Stator Assemblies

Fig. 6 shows a typical Pratt & Whitney stator vane assembly. These assemblies are normally brazed assemblies. Strap welding of the vanes to the outer hollow shroud is often employed. As a consequence of FOD or corrosion, many of these assemblies need extensive vane replacement. A typical damaged assembly is shown in Fig. 7. By proper control of welding, brazing, stress relief and machining, total vane replacement can be accomplished without deterioration of assembly, structural integrity, or dimensional control. A typical repair cycle includes removal of vanes by electrical discharge machining, replacing vanes in a predetermined fashion, setting vane angles to ± 20 min., tack welding vanes, furnace brazing in vacuum at 1850 F using Ni-Au or Au-Cu-Pd braze, cooling to 1650 F, quenching to below 500 F and stress relieving at 1050 F (also producing annealing) with appropriate thermal cycle, fluorescent magnetic particle inspect, repair snap diameters

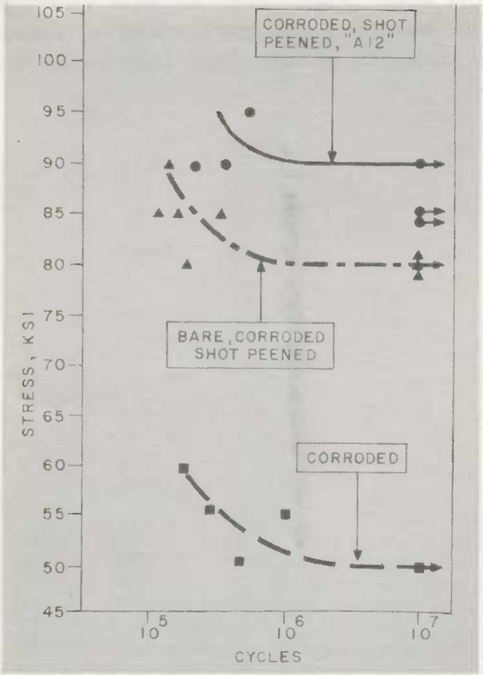


Fig. 11 Effect of corrosion, shot peening, and A12 coating upon fatigue strength

Fig. 12 Sacrificial protection of A12 coating during 120 hr salt spray exposure

by nickel plate or plasma spray (Metco Ni-Au), automatic glass bead peen, and corrosion coat. The complexity of maintaining dimensions of ± 0.002 in. on a 36 in.-dia is obvious. Fig. 8 indicates the control necessary on snap diameters for a group of Pratt & Whitney stators. Much of the welding, brazing, and stress relief fixturing used to accomplish these repairs must be designed empirically, since thermal transients often far exceed the effects of equilibrium thermal expansion. It is obvious as well that, at the brazing temperature (1800 to 1850 F), the stator structures have no appreciable strength. Fixturing is the key to any of these repairs, and the empiricism associated with fixture design is one of the limiting factors in the economic feasibility of specific repair procedures.

The inner air seal on the compressor stator is shown clearly in Fig. 9. In this case again, diameters of 16 in. must be machined and maintained to tolerances of + 0.005 in. Repair build-up of these seals through Metco Ni-Al plasma spray is a common practice.

Where aggressive, grit blasting (80 to 90 mesh Al_2O_3) is employed to remove effects such as corrosion pitting: surface finishing is often employed. Surface finishing of stator assemblies is accomplished utilizing SWECO vibratory polishing. This technique has also been found to be applicable to the polishing of compressor blading as well. Using aluminum oxide media, vibratory surface finishing of vane shrouds to from 100 to 120 to 30μin. rms has been accomplished.

Effect of Defects and Coatings on Fatigue Strength

Fig. 10 clearly shows the effect of a surface corrosion pit on the initiation and propagation of a fatigue crack in a JT3C compressor blade. The effect of pitting, heat-affected weld zone and surface scratches are shown in Fig. 11 (curve denoted corroded) with an endurance limit of 50 ksi. It is also clear that the majority of fatigue loss due to pitting may be regained by proper shot peening, in this case peening to an intensity of $10\overset{c}{A}$. To avoid corrosion pitting of the type indicated a sacrificial coating must be employed, since in a jet engine FOD and erosion are commonplace phenomena. Fig. 12 clearly demonstrates the sacrificial behavior of Chromalloy A12, a diffused aluminum coating, applicable to AMS 5616 steels. In this case, the aluminum coating corrodes preferentially to protect the basis uncoated steel. The major advantage of the A12 coating to standard NiCad coatings is that it retains sacrificial behavior at temperatures in excess of 600 F, whereas other coatings do not.

SUMMARY

Some of the techniques used in the repair

of gas turbine engine compressor components are described. Descriptions are given for the repair of disks, spacers, blades, and vane/shroud assemblies. A short discussion is also given on the effect of coatings and environmental damage on the fatigue strength of AMS 5616 compressor blading.