Maintenance and support of mature gas turbines

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ABSTRACT

With the acquisition of parts of Alstom Power, Siemens took responsibility for the support of a diverse range of gas turbine packages built by GEC, English Electric and AEI. Several hundred packages were built in Leicester, Lincoln and Trafford Park. They mainly consisted of aero-engine derivatives driving an in-house supplied power turbine but several industrial turbine models were also designed and built. The acquisition included the intellectual property rights.

Whilst production finished in the '90’s, and many were sold over thirty years ago, there remains a significant number in operation that need spare parts, service and technical support.

We describe the special needs of supporting these long service units and the issues that are raised. After a discussion of the lifing methods for older machines, we go on to describe selected examples of service issues. Subjects covered include component obsolescence, material changes, repair versus replacement, retrofits and upgrades.

The advantages of retaining an OEM based design authority, with access to the original design data as well as access to current materials and design data is illustrated.

Whilst most units were sold for base-line duty, many were for stand-by or emergency operation and the special problems of that duty are discussed.

The paper should be of particular interest to operators of all Siemens legacy equipment, particularly GEC units, but the principles apply to other units of the same era.
1 INTRODUCTION

1.1 History
At the beginning of a new technology many companies start-up or move into the field seeking new markets and new profits. After a time the industry rationalises, companies fail or merge or both. Factories close. The reorganisation of companies is reflected in the change in products made. Duplication is eliminated, unsuccessful types dropped. The gas turbine industry is no exception; (Figure 1) shows the way in which four brands mutated into one, Siemens. The process bequeaths a legacy of many engine types to the inheriting company, in our case Siemens Industrial Turbomachinery.

Siemens hold intellectual property rights to the products delivered under the Ruston, GEC, English Electric, European Gas Turbines (EGT), and AEI banners as well as the range of Alstom industrial gas turbines. In this paper we attempt to show the value of intellectual property and archive data in supporting the gas turbine user.

1.2 Design methods
This paper shows examples of how Siemens Industrial Turbomachinery supports the range of models made by the preceding companies. The examples are from the GEC gas turbine range, the largest of the legacy brands. Support extends to earlier brands as industrial gas turbines, designed for a life of 10 to 15 years, remain in service after 30 years. The design dates back into the age of the slide rule and the logarithm. Stressing in some cases is a simple load over area calculation. Creep life was estimated by Larson-Miller criteria, and fatigue life ensured by the application of conservative safety factors. Test data for these older turbines are available, but the quantity is not the quantity collected today. However, good practice remains good practice, and information on temperatures, pressures and frequencies provide a sound background for solving today's service problem.

2 THE BENEFIT OF ARCHIVES; ERB1 OFFSHORE
Early one winter morning an offshore compressor set tripped with high vibration of the ERB1-24 power turbine. Re-starts were attempted but were unsuccessful, the vibration remained. The turbine was opened to investigate the cause and it was found that an ERB1 2nd stage rotor blade had failed damaging other 2nd stage blades and nozzles.

The blade had failed in the neck between the top fir-tree lobe and the underside of the platform displaying a characteristic fatigue pattern (Figure 2). The rotor was sent for repair, the blade root section and aerofoil remains were examined in the Metallurgical Laboratory at what is now Siemens Industrial Turbomachinery.

Examination of the failed blade confirmed that the fracture surface was characteristic of high cycle fatigue (HCF) over approximately 70% of its surface. The fatigue region propagated from a single point that showed no obvious defect. An area near the centre of the crack surface revealed a change of striation spacing. This was described as a possible
indication of short-term propagation in low cycle fatigue (LCF). However, there was no other evidence to support LCF as the failure mechanism.

Chemical analysis of the blade root and hardness checks confirmed that the material was consistent with Nimonic 80A to the original specification.

Running logs and operational data showed the blade was in the fleet lead engine accumulating 170,000 hours equivalent running. No one involved in engineering support for the ERB1 could recall a similar fracture. To understand this incident the company archives were searched for design and test data.

The search uncovered a similar incident. Twenty-three years earlier the ERB1 turbine of an onshore compressor set failed after just 1,343 hours of operation, mostly at 6480 rpm. A 2nd stage rotor blade had separated at the base of the aerofoil. Non-destructive testing found another cracked blade. The crack in this second blade was in the root between the top fir-tree lobe and the underside of the platform. When the crack was opened the metallurgical examination indicated high cycle fatigue (HCF) as the driving mechanism with no obvious defect at the origin. This root crack was similar to that suffered twenty-three years later.

The early investigation concluded the positions of cracking and the power turbine speed were all consistent with resonance of the blade fundamental mode with the 3rd engine order. To solve the problem the mean blade frequency was increased and the 3rd engine order moved above the maximum running speed by modest re-profiling of the aerofoil. Bench testing and further strain gauging of two engines confirmed that the resonance frequency had been shifted by the desired margin.

This older investigation used what were then novel techniques, such as holography, to confirm analytical results. The designers exercised the duty of care; by combining techniques the vibration characteristics were established.

The redesign had pushed the 3rd engine order out of the operating range, but the 4th remained. The fundamental blade frequency passed through that engine order on start and shut down giving brief periods of excitation. It seemed this blade suffered accumulative fatigue damage on each cycle of start from rest. Combining archive data with operation information we concluded this blade has a finite life. We were able to advise other operators of the problem and so help them avoid similar incidents. To date the five operators of the ERB1 fleet have accumulated 2,274,000 hours running.

3 LONG LIFE AND SHORT RUNNING; EASI COMPRESSOR SET

The ERB1 incident described above is an example of a problem only uncovered by extended running. There is another class of problem associated with mature engines; damage on stand-by. This should not be a surprise, if a new engine is sold and it is not immediately installed then it is prepared for storage. This may entail sealing the unit in a container with a dry or inert atmosphere, to exclude moisture and so limit corrosion.
If an engine is required for short notice stand-by operation however, it may sit for extended periods with the inlet and exhaust open. The inlet of an industrial gas turbine is partially protected by the filter array. The exhaust may have a quick-opening flap, but it is unlikely to be hermetically sealed. In these circumstances atmospheric air will freely enter the turbine. If the engine is installed in a dry climate, like the deserts of Colorado, this will be no problem, but most climates are likely to be damp. Open to the air, moisture can condense on internal parts. Once a corrosion pit forms, that in turn becomes a preferential site for droplet formation and corrosion accelerates.

The ability of turbine components to resist corrosion varies. High temperature blading and combustion parts in nickel alloys are inherently corrosion resistant. Shafting in steel is protected in part by lubricating oil flowing from the bearings. Designers will not normally consider corrosion under standby conditions, but all designers will consider first cost. With cost as a consideration and their steam turbine heritage, designers of the EAS1 used a CrMoNiVa steel for the disc. This steel is a good choice for engines with high usage, moisture in the hot disc cooling air does not precipitate but at ambient conditions water will condense on the disc, giving rise to corrosion.

A routine overhaul of an EAS1 engine uncovered a disc with significant corrosion and in need of replacement. The equivalent running hours of the unit were short; the hours spend on unprotected standby long. The disc life is normally estimated at 150,000 equivalent hours, the short running life of this disc suggested that each standby hour consumed the equivalent of 0.3 hours of running.

The engine was an early EAS1 unit and the disc did not have corrosion protection. Later discs are coated and this is now the standard specification for spare discs. The coating will protect the web, but the high loading in the fitrees can extrude the soft coating. EAS1 users’ are advised to include a check for disc corrosion as part of regular servicing.

4 NOZZLE REPAIRS

The conservative firing temperatures and moderate stress levels mean that hot gas component repairs are relatively uncommon. This is particularly true of the power turbines fitted to the aero derivative packages, where some units have recorded in excess of 100,000 operating hours, without needing any major repairs.

Nevertheless, to assist operators with predicting replacement times of critical components, so that budgets can be arranged in good time, two bulletins have been issued: SB/ERB/98-010 is for RB211 packages and SB/EAS/05-004 for EAS1 (Avon) packages. It should be noted that the expected lives quoted therein are prudent fleet-averaged figures; their purpose is to act as a guide to the recommended change-out times. Actual lives are subject to a whole range of variables and could be longer or shorter. We are willing to talk to customers individually, to advise them on the likely impact of specific site factors.
In respect of blading, the need for a repair is often following failure of the gas generator, which results in severe impact damage through the PT blading.

Whilst our internal repair schedules allow light repairs to some areas of the rotor blades, these unrestrained cantilevered designs are very vulnerable to vibration if they are modified from design and blending or repair can do just that by moving the blade into a critical frequency zone. As a result few rotor blades are repaired and change-out for new is the preferred route.

In respect of nozzle blades, whilst new items are still supplied and fitted, repairs are also feasible.

The blades are lightly stressed with only the gas bending loads present and any thermal loading that occurs as the nozzle assembly heats and cools. The materials used are quite weldable and in many instances the structure was manufactured originally using welding processes. Hence post-repair cracking is not usually a problem, provided the material has been correctly heat treated, following repair and compatible filler wires are used.

Damage is often most severe in the region of the aerofoil trailing edges and here a variety of techniques can be used. For minor damage the profile can be regained by building up with weld and blending back. This is time consuming as the heat input levels must be kept down to avoid distortion and there are often several iterations before the final profile is obtained. Great care must be taken also to maintain the correct blade geometry, in particular the blade exit angles and throat dimensions. Variations in these values, outside of the original production tolerance, could possibly lead to cyclic loading on the downstream rotors blades, which might in turn excite the blades and cause failure. Having the blade design drawings in-house means that these parts can be checked accurately, regardless of the condition as received.

The degree to which repair can be taken can be illustrated in the attached example (Figure 3) where both the leading and trailing edges have been completely lost due to impact damage. Whilst these would normally have been considered beyond recommended or economic repair levels, the customer still wished to proceed. Repair by building-up with weld was out of the question due to the time involved, loss of accuracy, and distortion that would inevitably occur. Instead, replacement inserts were wire-cut using the original profile drawings and after suitable preparation, tacked and welded into place. With such heavy welds distortion is still inevitable. Counter measures were taken to avoid this but to measure and correct, special jigs had to be made using the original blade drawings. After a final check of the critical geometry, plus other cosmetic work, the nozzles were returned to service, where they have operated on base-load without incident.

Whilst many repairs are feasible on this standard of parts, and material can be heat treated to restore many of the original properties, the life-limiting factor is often the progressive distortion that inevitably results from repeated repairs or general wear and tear. It is hence still appropriate to offer new parts as well and for a critical machine application, holding a spare rotor and nozzle still represents the quickest route to get a unit back into service.
5 DESIGN CHANGE IN MATURITY; ERB1 STATOR RING

The first stage nozzles of the ERB1 power turbine are, like many early turbines from English Electric and GEC, constructed with individual blades held in a stator mounting-ring. The arrangement reduces cost as only the nozzle blade and the shroud need be in high temperature nickel alloys. The stator ring being remote from the gas path was made in alloy steel, FV448. The stator ring of the ERB1 is necessarily a substantial component and is used to carry the outer section of the turbine inlet duct. As it is exposed to the gas stream this duct work is made from Hastelloy. This arrangement seemed to work well at first but as the service experience on the ERB1 accumulated, problems appeared with the duct. The rear flange distorted badly, the bolt holes became elongated radially. There was clearly movement between duct and stator ring, differential thermal expansion was too great. The cause was straightforward, the co-efficient of thermal expansion of FV448 is $12 \times 10^{-6}/\degree C$, for Hastelloy the figure is $18 \times 10^{-6}/\degree C$. To reduce or eliminate the damage a design change was needed. The degree of damage suggested it must be a fundamental change, and the decision was made to offer a stator ring in Inco 718, material with an expansion coefficient close to $18 \times 10^{-6}/\degree C$.

In gas turbine aerodynamic design it is normal to set the dimensions of the hot gas path and back calculate the thermal expansions to set the cold dimensions. This ensures each turbine stage has the correct swallowing capacity. Before introducing the change, nozzle expansions were recalculated to ensure acceptable nozzle size. Service bulletin SB/ERB/99-001 gave notice of the change. Recognising that this was a significant change and that a service bulletin is necessarily a brief document, the details of the modification were given in a presentation to users. That presentation was well received and all ERB1 users made the change.

6 RETROFITS AND REPAIRS

Whilst a policy of offering repair or replacement parts to the original design is the preferred practice in most cases, controls and instrumentation represents an area where this is not the most satisfactory solution.

The electronic control systems supplied by GEC usually consisted of an in-house design, built around hardware sourced from a number of suppliers, both internal and external. Whilst core controls, such as the governor and sequencing were based on hardware designed and built in-house, other “peripheral” areas such as vibration and fire and gas detection were often completely bought-in systems, suitably interfaced to the core controls.

Early governors were simple analogue affairs, using proprietary circuit boards and mainly, standard components but the final development was an in-house designed and built digital governor, featuring a number of integrated circuits and proprietary parts.

In common with most electronic equipment throughout this era, many of the integrated circuits and most of the special components are no longer available, with suppliers either...
no longer being in business, or unable or unwilling to support the equipment in question. Whilst the controls have given good reliability overall, it has proved increasingly difficult of late to offer repairs or replacements.

As a result, a service bulletin was issued to Avon, RB211 and Olympus package users’ in June 2005 advising that Siemens would no longer be able to support these controls or the earlier pneumatic and hydraulic systems. The recommended solution given was to replace the controls suite with new.

Fitting a modern controls system offers a number of advantages; in particular, new features can be incorporated to bring it into line with current operating expectations. Advanced data logging is one such example.

With all the enhancements available, it must be borne in mind that turbines of this era were supplied with relatively basic instrumentation by today’s standard, so to take full advantage; it is worthwhile fitting new or additional instrumentation at the same time.

Introducing shaft displacement vibration equipment in place of casing accelerometers could be such a change. However, modification of core control instrumentation or change to controls philosophy must be approached carefully if machine integrity issues are not to occur subsequently.

Finally a new controls system is far simpler to integrate within a redeveloped power station, of which these turbines often form part. The same standard of hardware may be feasible throughout, reducing training necessary for staff and, in some cases, the spare parts holding. Designing a new system is a combination of using the data available, the customer's requirement and current design practice, producing a bespoke package built largely on current turbine controls that will be available for some time in the future.

7 CONCLUSION

In this paper we have attempted to give an overview of the special requirements of supporting mature gas turbines. There are faults that will never be uncovered by prototype testing. These faults only show up after thousands of hours of running or simply just standing. The technical solutions vary, from changes in service regime to material replacement. Confidence in the solutions is increased as an OEM has not only the immediate service experience to draw on but also design and test data, the intellectual property of the preceding companies.

There is a special class of problem in supporting mature engines; component obsolescence. This particularly affects the early digital electronic controls, but it can arise with any form of bought out component. Once again, the archive of intellectual property contributes to the solution.

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Though problems vary there is one constant; communication with the user. An OEM may devise solutions to service problems, but they are of no value unless the user knows of the solution and is willing to make the change.

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Fig. 3 Nozzle repair.