Modernization of MS3002 gas turbines produced by GE from 1951 to 1973 has been accomplished with the application of advanced technology components in a redesigned turbine hot section. Texas Eastern installed the first modernization package in 1986 and now have 10 units in service totalling more than 135,000 operating hours.

This paper presents the user's motivation to refurbish 30 year old gas turbines, including details of the uprate installation and subsequent operating experience. Specifics of the advanced technology components in these units are provided including their impact on unit performance and reliability.

**INTRODUCTION**

First introduced in 1951, the GE MS3002 gas turbine has undergone performance improvements with each successive model, as shown in Figure 1. Earlier models "A" through "G" were all built with essentially the same compressor air flow and major turbine components. Improvements in performance were achieved through application of high temperature alloys and increases in turbine firing temperature. The current production model "H" and its predecessor model "I" (introduced in 1969), are based on a redesigned turbine section featuring a higher compression ratio and supported by four bearings instead of the five used in the earlier units. With the exception of the compressor, few model "H" or "I" components physically fit into the earlier models. After many thousands of fired hours, major components such as turbine wheels were approaching the end of their useful lives, and parts for early models had become less readily available.

Texas Eastern began purchasing GE MS3002 model "G" gas turbines in 1955 for use in gas pipeline pumping stations, and by 1962 the fleet had grown to 21. By 1985 individual turbines had accumulated between 169,000 to 241,000 fired hours, while thermal efficiencies averaged about 27%. However, these turbines had a composite wheel design and they would require inspection or replacement at the next major overhaul interval. Texas Eastern had two options; it could replace components in the turbines, though some components were not readily available, or it would have to replace the turbines completely.

General Electric offered a third alternative for operators of more than 200 MS3002 models "A" through "G" with the commitment in 1984 to design a new turbine section for these units. It would be an extensive modernization renewing the high maintenance hot gas path components based on a new aero design using 1980’s technology to provide substantial improvements in performance and extended maintenance intervals. With a guaranteed 32% thermal efficiency (at specified conditions) and projected reliability of a new machine, Texas Eastern chose to uprate 10 of their MS3002 model C's in 1986.

The discussion that follows describes the generic uprate, applicable to all models "A" through "G", as well as the Texas Eastern application.
UPGRADE PERFORMANCE GOALS

Advanced technology developments for MS3002 models "A" through "G" began with a new aerodynamic cycle based on Texas Eastern's requirement for fuel efficiency improvement at the original Model "C" output rating of 8,000 hp. The resulting turbine design, however, provides fuel efficiency and increased output options over the entire operating range for both regenerative and simple cycle designs.

A major design objective was commonality of new components for all of the models to maximize and ensure availability of these parts. This was achieved in every respect, with the exception of some minor interface seals and piping for specific applications.

Figures 3 and 4 show the uprate performance capability for regenerative and simple-cycle turbines firing at 1628°F and 1643°F respectively.

Models "A" through "G" can now be uprated to the maximum regenerative or simple cycle horsepower shown in Figures 3 and 4 with the associated thermal
efficiencies. However, the combustion system, number of compressor stages and/or exhaust diffuser arrangement of some units may reduce their uprate performance potential.

The following design parameters were established:

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Regen. Cycle</th>
<th>Simple Cycle</th>
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</thead>
<tbody>
<tr>
<td>Nominal Compressor Shaft Speed</td>
<td>6520 RPM</td>
<td>6900 RPM</td>
</tr>
<tr>
<td>Minimum Compressor Shaft Speed</td>
<td>5900 RPM</td>
<td>5900 RPM</td>
</tr>
<tr>
<td>Maximum 100% Load Shaft Speed (with 105% continuous operating capability)</td>
<td>6000 RPM</td>
<td>6000 RPM</td>
</tr>
<tr>
<td>Maximum Exhaust Temperature</td>
<td>1000°F</td>
<td>1000°F</td>
</tr>
<tr>
<td>Maximum Firing Temperature</td>
<td>1628°F</td>
<td>1643°F</td>
</tr>
<tr>
<td>Maximum IGV Angle</td>
<td>75°</td>
<td>81°</td>
</tr>
<tr>
<td>Minimum IGV Angle</td>
<td>63°</td>
<td>75°</td>
</tr>
</tbody>
</table>

Figures 3 and 4 are based on the nominal compressor shaft speed at maximum load shaft speed, firing temperature, IGV angle and exhaust temperature at NEMA conditions with no inlet or exhaust pressure drop. Regenerator effectiveness of 86% is assumed for the regenerative cycle.

The following Texas Eastern uprate design-point parameters results in a thermal efficiency of 32%, at original NEMA output of 8,000 hp. Texas Eastern's objective was modernization of turbines at their original horsepower, minimizing changes in the load compressor and permits.

Compressor Shaft Speed | 6,280 RPM |
Load Shaft Speed       | 5,700 RPM |
IGV Angle             | 75°       |
Firing Temperature     | 1,600°F   |
Exhaust Temperature    | 1,000°F   |
NEMA Conditions        |           |
Inlet Pressure Drop    | 0         |
Exhaust Pressure Drop  | 0         |
Regenerator Effectiveness | 86%     |

MAINTENANCE GOALS

When uprating MS3002 units with advanced technology components, major inspections are only required every 48,000 fired hours (based on baseload operation with natural gas). Combustion inspection intervals have been extended up to 50%, with liner inspections recommended at 12,000 fired hours and transition piece inspections at 24,000 fired hours. Hot gas path inspections have been eliminated with the uprate. Inspection interval improvements based on advanced technology parts are shown in Figure 5.

MS3002 UPRATE WITH ADVANCED TECHNOLOGY COMPONENTS

The new MS3002 aerodynamic design resulted in significant design change of gas path components in order to meet performance goals. Maintenance and reliability objectives also contribute to the turbine design, as shown in Figure 2. A typical original design turbine section is shown in Figure 6.

In the new design, the original water cooled, welded turbine shell was replaced with an air cooled, nodular iron cast shell which is arranged in the factory, complete with first and second-stage shrouds, second-stage nozzle partitions and interstage diaphragms. Figure 7 shows the turbine arrangement partially assembled. The turbine shell is designed as a drop-in replacement for the original with respect to turbine frame and exhaust frame vertical bolting.

Extra stock is provided on the turbine shell to accommodate resurfacing of mating flanges that may have distorted during service. The aft turbine shell flange area is air cooled with tenth-stage extraction air from the axial flow compressor. This cooling air is then delivered, in series, to the interstage diaphragm for aft and forward wheel space cooling. Elsewhere in the turbine shell, insulation packs are used to control temperatures.

Tubes for removable thermocouples enter the interface wheel spaces via support pins. Borescope inspection holes through the turbine shell and shrouds make it possible to view first and second-stage turbine buckets.

The 32 variable second-stage nozzle partitions and shafts are integrally cast from N155 alloy. The control ring is roller supported from the turbine shell. At Texas Eastern, dual hydraulic cylinders mounted on the turbine shell use existing 300 psi hydraulic oil to drive the control ring and position second-stage nozzle partitions. New linkages provide feedback to the existing control system on Texas Eastern units. Other uprate applications integrate controls upgrade packages and, in some cases, use different hydraulic actuators.
Increased Nozzle Life

Several new design factors resulted in increased nozzle life. The first-stage turbine nozzle consists of 24 two-vane segments (Figure 9) cast from FSX-414 material. The reduction from the original seven vanes-per-segment significantly increases the number of calculated thermal cycles to sidewall crack initiation—a design similar to first-stage nozzles in the latest GE gas turbine products.

Air cooling, which controls metal temperatures and associated thermal strain, also contributes to long nozzle life. A sheet metal core plug distributes impingement cooling on the interior of each vane, and cooling air exits the vane from holes near the trailing edge on the suction side.

Nozzle sidewall contours accommodate a larger gas path diameter which was required to achieve performance objectives. The nozzle is supported from the turbine frame by a new nozzle support ring which contains the stator seals and two thermocouple wells for monitoring wheel space temperature.

Rotor Replacement

The MS3002 uprate package calls for replacement of the existing high-pressure (HP) rotor with an M152-alloy first-stage wheel, new buckets, shaft, rotor shim and bolts. Replacement of the original composite wheels was a specific requirement of Texas Eastern.

Cast of GID111 alloy, the 92 first-stage buckets are solid to minimize damage by foreign objects, and are designed with an integral shroud to maximize performance (see Figure 10). A three-tang dovetail wheel attachment is used, axial constraint is achieved with twist locks. The shaft is a one-piece design similar to those found on later model "F" machines.

A modification to #3 bearing seals is required on some models to fit the uprate shaft. Figure 11 shows the uprate HP and low-pressure (LP) rotor assemblies in a unit with upper casings removed.

A new LP rotor design is also required, with an M152-alloy second-stage wheel, new buckets, shaft and associated hardware. The 80 shrouded second-stage buckets are also cast of GID111 alloy (Figure 12) and the same dovetail attachment in stage one is used for the second stage, but is employed 10° of f axis to accommodate bucket airfoil geometry. Axial constraint is achieved by snap ring similar to other current production turbines.

The shaft fits in the existing #4 and #5 bearing and is equipped with a new overspeed bolt assembly, speed ring and coupling hub. The uprate wheel and shaft geometry requires new wheel space seals and #4 bearing forward side seal. The change in the mass of the rotor as the result of these advanced design and materials modifications is relatively small, resulting in very little change to the rotor dynamics.
Frame Modifications

Uprate modifications to the exhaust frame include a new, extended diffuser to improve efficiency (Figure 13) and minor changes on both the inner and outer side walls to better match the second stage bucket exit annulus. The forward vertical flange is skim cut to remove any existing distortion and potential leakage when assembled to the new turbine shell. Similar relief is cut on the aft surfaces of the turbine frame that join the turbine shell and nozzle support ring.

Other modifications to the turbine frame provide replacement insulation packs, resizing combustion can mounting bolts, and provisions to accommodate uprate transition pieces. In some models there were changes to sealing air piping for bearings #2 and #3.

Combustion System Upgrade

The gas turbine combustion system is extensively upgraded as illustrated in Figure 14. Hastelloy X is used for the combustion liners, and other changes for the liners include louvered design and features found on later models, such as the hula seal on the transition piece and splash-plate cooling at crossfire tube locations.

The liner length, extended to the combustion elbow, eliminates a short #2 liner originally used in the turbines. Complete inner and outer elbow assemblies are supplied, upgraded with Hastelloy-X material for the inner elbow and chrome-molybdenum alloy for the outer elbow in regenerative cycle applications. The #3 liner, extending from the elbow to transition piece, is air cooled.

**MS3002 Upgrade Exhaust Diffuser**

The uprate transition piece incorporates the latest in duct shape design and is fabricated from heavy gauge Hastelloy-X material. Other transition piece features include new side seals, a floating outer seal and increased corner radii, to help extend life expectancy. The transition piece exit radii provide an improved gas path flow match with the first-stage nozzle entrance, which remains unchanged from the original design. The improved transition pieces can be used with early MS3002 units even without the other uprate modifications.

Crossfire tube assemblies were replaced with a three-piece design similar to those used on later MS3002 models. Carbon steel headers, approaching the end of their useful lives, were replaced with upgraded headers made from chrome-molybdenum alloy. They were equipped with later model access covers. Fuel nozzle tips were replaced with new gas hole sizing to match uprated fuel flow requirements.

Control system modification on Texas Eastern units provide over-temperature protection using fast-acting extended exhaust thermocouples and the TEMPRO Option I package. Some machines were also equipped with the TEMCON I and II electronic modules, which eliminate pneumatic components from the fuel regulator control system. Other MS3002 uprates have incorporated more sophisticated controls systems, using microprocessor-based GE Mark IV Speedtronic controls.
MS3002 Upgraded Combustion System

During the upgrades of the Texas Eastern units, the turbines were removed from their bases and sent to a GE service shop for disassembly, inspection and the installation of the advanced technology components. The turbine frame and exhaust frame flange surfaces were machined to restore flatness of joints. Uprate components, such as the exhaust diffuser and insulation packs, were installed and compressor rotors and stators were rebladed with the latest replacement material.

Optical alignment of bearings and casings was done during unit assembly on a special base. Casings were dowelled and clearances checked upon installation of rotors. Figure 15 shows the turbine rotors in the lower half. All casing bolts are replaced with current GE design standard 12-point nuts.

Because of lift limitation at the site, the upgraded turbines were disassembled at the service center for separate shipment of rotors, compressor and turbine subassemblies. An optical alignment of turbine sole plates was made on site before installation of the upgraded turbines. Upgraded combustion headers, elbows and liners were field assembled to the turbines, and cooling and sealing air piping, hydraulic oil and fuel piping modifications were installed. A field alignment of the turbine load equipment was performed, and control modification installation and checks complete the uprate.

Six of Texas Eastern’s earliest MS3002 units were uprated in 1986, two more in 1987 and two in 1988.

OPERATING EXPERIENCE

Performance tests conducted on Texas Eastern units have established that the uprates met the guaranteed 32% thermal efficiency (regenerative cycle) at 8,000 horsepower and reference conditions. Power was measured by torque meter and fuel flow was measured by turbine flow meter and orifice differential pressure. Relative to the initial estimate, the compressor (HP set) speed was increased approximately 200 RPM to 6280 RPM, while maintaining constant exhaust temperature, to provide rated output. There have also been several minor turbine design changes introduced in the last of Texas Eastern’s initial order of 10 uprates to enhance performance.

The first two of Texas Eastern’s uprated MS3002’s have each accumulated over 22,000 fired hours and all units are operating reliably. A few changes were required, primarily on the first four units, that were attributed to the learning curve of an extensive modernization program conducted without benefit of fired factory tests.
The MS3002 advanced technology uprate has modernized ten Texas Eastern turbines with major new components, improving performance and extending maintenance levels.

Texas Eastern's management is pleased with the efficiency and reliability obtained through GE's uprate program and have purchased five additional uprate packages that will be in service in 1990.

REFERENCES


3. Freeman, M.A., "MS3002 Gas Turbine Modernization with Advanced Technology Parts" GER-3527 (1987)