GAS TURBINE PERFORMANCE UPGRADE OPTIONS

By Jeffrey Phillips and Philip Levine

This article reviews some specific methods for boosting power and improving heat rate − either by increasing inlet air density or by boosting specific power. While the techniques mentioned here are by no means the only ones available to gas turbine owners, they represent some of the most cost-effective upgrade options.

While some of the gas turbine upgrade options reviewed here are clearly less expensive than others, there is no one "best" technique (table). The best option for a particular gas turbine will depend on its age, location, and operating cycle.

Comprehensive Upgrades

Comprehensive upgrades of gas turbine involve the replacement of "flange-to-flange" parts with more advanced designs. Because late-model gas turbines already incorporate advanced technology, these comprehensive upgrades apply only to older gas turbines that are part of a series or model line that the original equipment manufacturer (OEM) has redesigned. Examples of these model lines include the Frame 7 and 9 series supplied by GE Power Systems, Schenectady, NY, and the W251 and W501 series supplied by Siemens Westinghouse Power Corp., Orlando, Fla.

An upgrade can be applied to individual components or to the entire engine. Examples of components that can be upgraded include:

- Inlet guide vanes, which allow more air flow
- Improved seals, tighter clearances
- Combustion liners and transition pieces, enabling higher firing temperatures
- Turbine blades and vanes, also enabling higher firing temperatures

The results of a comprehensive upgrade on performance depend, of course, on what is included in the project. However, the upgrades of eight GE Frame 7Bs by Houston Light & Power Co. (now Reliant Energy HL&P, Houston Texas) in the 1990s provide a good example of what can be accomplished.[1] Reliant replaced the combustion liners, transition

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[1] J. Svatek, M. Elliott, P. Crabtree, G. Jurczynski, and J. Johnston, "Results of the GT Prime Program Improvements to General Electric MS7001B Gas Turbines at the Houston Light and Power T.H. Wharton Site", ASME Technical Paper 97-GT-450, June 1998.

pieces, 1st stage turbine vanes, and 2nd stage vanes and blades with Frame 7EA parts. This allowed operators to increase the firing temperature of the machines by 170 deg F.

After the upgrades, the eight machines yielded power increases of 16 to 26%, while the heat rate decreased by 4.5 to 11% − improvements that are approximately three times greater than what could have been expected from a normal overhaul using new Frame 7B parts.

The cost for the upgrades divided by the increase in power output was approximately \$250/kW. This low figure actually overstates the incremental cost of the additional capacity because it does not account for the expenses Reliant would have incurred if it had performed a normal overhaul using 7B parts.

One upgrade option Reliant did not choose is high-flow inlet guide vanes (IGVs). This option can be very cost effective. The thinner vanes of advanced designs allow more air flow to pass through the turbine, compared to older IGVs. On a Frame 7B, you can expect a 4.5% boost in power and a slight improvement in heat rate − approximately 1%. The cost of new IGVs typically is less than \$100/kW.

Hot Section Coatings

Another option for upgrading gas turbine performance is to apply ceramic coatings to internal components. Thermal barrier coatings (TBCs) are applied to hot section parts in advanced gas turbines. These same coatings can be applied to the hot sections of older gas turbines in the field. The TBCs provide an insulating barrier between the hot combustion gases and the metal parts. TBCs will provide longer parts life at the same firing temperature, or will allow the user to increase firing temperature while maintaining the original design life of the hot section.

A recent analysis sponsored by the Combustion Turbine Combine Cycle Users Organization showed that adding a 10 mil coating to the 1st stage blades and vanes of a GE Frame 7EA would allow an increase in firing temperature from 2020 deg F to 2035 deg F. The report calculated that this small increase could provide \$4 million of net revenue over the life of the coating.[2]

A similar study conducted by Fern Engineering, Inc., Pocasset, Mass., for the Electric Power Research Institute, Palo Alto, Calif., concluded that the addition of TBCs to a GE Frame 7B would provide an increase of 5.5 MW in power, at an incremental cost of \$140/kW. Note that this is cheaper than the cost of a comprehensive upgrade.

Compressor Coatings

Coatings can also be applied to gas turbine compressor blades (the “cold end” of the machine) to improve performance. Unlike hot section coatings, the purpose of compressor blade coatings is not to insulate the metal blades from the compressed air. Rather, the coatings are applied in order to provide smoother, more aerodynamic surfaces, which increase compressor efficiency. In addition, smoother surfaces tend to

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[2] Vandergriff, D., “The Life Cycle Value of TBC Coatings on MS7001E/EA 1st Stage Nozzles and Buckets”, Power-Gen 2000 Proceedings, Orlando, FL, Nov. 2000.

resist fouling because there are fewer "nooks and crannies" where dirt particles can attach.

Some coatings are also designed to resist corrosion, which can be a significant source of performance degradation, particularly if a turbine is located near saltwater. Corrosion-resistance tests on the 3rd stage high-pressure compressor vanes of a Rolls Royce Mainville, Ohio, RB211 revealed dramatic improvements with a coating. The tests, conducted by Sermatech International, Limerick, Penn., subjected the vanes to five cycles of exposure to salt-saturated fog followed by simulated full-load operation. One compressor section had no coating; another was coated with a 1.3 mil layer of SermeTel 5380DP – an aluminum-filled ceramic primer (Figure 1).

Figure 1 – Corrosion-resistance tests conducted on high-pressure compressor vanes revealed the significant benefit of coatings. The upper section has no coating; bottom section was coated with SermeTel 5380DP.

Florida Power & Light (FP&L), Juno Beach, Fla., has evaluated the benefit of the same Sermatech coating on the axial compressor of W501F gas turbine. The utility coated one of two units that were in combined cycle operation. Both machines were overhauled at the same time, and the same maintenance was performed on each machine, except for the smooth coating that was applied to the compressor of only one of the turbines.

FP&L then measured operating efficiencies at peak loads. The results of the tests showed that the unit with the coated compressor had:

- Higher compressor efficiency of 0.64%
- Better heat rate, 0.58%
- Higher power output, 1.26%

While these improvements may not be as great as those that can be achieved with hot section coatings, they are obtained at a relative low cost. The incremental capital cost of the capacity boost was approximately $60/kW, and payback for the cost of applying the coating occurred in just 6 months.

Applying compressor coatings on much older gas turbines can provide much larger gains than those achieved by FP&L. The compressor airfoils of older turbines tend to be rougher than a newer model simply because of longer exposure to the environment. In addition, the compressor of older models consumes a larger fraction of the power produced by the turbine section. Therefore, improving the performance of the compressor will have a proportionately greater impact on total engine performance.

For example, Turbine Resources Unlimited (TRU), West Winfield, NY, recently completed a compressor overhaul of two W501AA gas turbines for a customer in New Jersey. According to company president Bill Howard, TRU applied its compressor lubricity coating, TRU-Flow 2000, to the compressor diaphragm sections and custom-fit the radial seals to optimize clearances. The combination of these two actions allowed its customer to produce 4 MW of additional power from each turbine − an increase of 6% over previous power levels.

Gas Turbine Upgrade Options

Option	**MW Impact, %**	**Heat Rate Impact, %**	**Capital Cost, $/kW**
Comprehensive Upgrade	+10 to +20	1 to 5	150 to 250
High-Flow IGVs	+4.5	1	< 100
Hot Section Coatings	+5 to +15	0.5 to 1	50 to 100
Compressor Coatings	+0.5 to +3	0.5 to 3	50
Inlet-Air Fogging	+5 to +15	1 to 5	50 to 100
Supercharging Plus Fogging	+15 to +20	4	200

Raising Air Flow

Perhaps the simplest way to increase the power output of a gas turbine is to increase the mass flow through the machine. And one of the most popular ways to do this is to increase the density of the inlet air − by evaporative cooling, mechanical chilling, or inlet fogging (Figure 2).

Figure 2 − A fogging nozzle array inside a GE 9FA filter house (right) and a high-pressure fogging pump skid (left). Photos: American Moistening Co., Pineville, NC

A more novel approach, but one that deserves more attention, is supercharging. Supercharging of a gas turbine entails the addition of a fan to boost the pressure of the air entering the inlet of the compressor by 40 to 80 in. H_2O. In some ways, supercharging mimics the upgrade tactic used by several OEMs of adding a "zero stage" to the compressor. However, in the case of supercharging the additional stage of compression is not driven by the main gas turbine shaft, but rather by an electric motor. The parasitic power of the fan motor is less than the additional output of the gas turbine, so the net result is a capacity boost.

The impact of supercharging is especially significant if it is coupled with inlet fogging downstream of the fan. The fan stage increases the air temperature, which increases the difference between the dry bulb and wet bulb temperatures. This allows more cooling to be provided by the fogging system.

One application of supercharging was on a W301G combined cycle in San Angelo, Texas, in the 1960s. However, analysis has shown that the net power boost from supercharging increases with turbine firing temperature (Figure 3). As a result, the cost per kilowatt of supercharging should be significantly less than it was for turbines built 40 years ago.

At least one company has recognized the potential impact supercharging could have on advanced gas turbines. Enhanced Turbine Output, LLC (ETO), Washington, DC, has patented a design of a supercharging system[3] and is actively marketing the concept to turbine owners. According to William Kopko, ETO's VP of engineering, an ETO variable supercharging and fogging system could increase the output of a GE 7FA by 20% beyond fogging alone in the Memphis, Tenn. climate while improving the heat rate

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[3] William L. Kopko, "Supercharging System for Gas Turbines", US Patent No. 6,308,512, Issued October 30, 2001.

by 4%. The ETO system would achieve this improvement without entraining any water into the turbine, despite the large increase in total fogging. The estimated cost for the increased power is a low $200/kW.

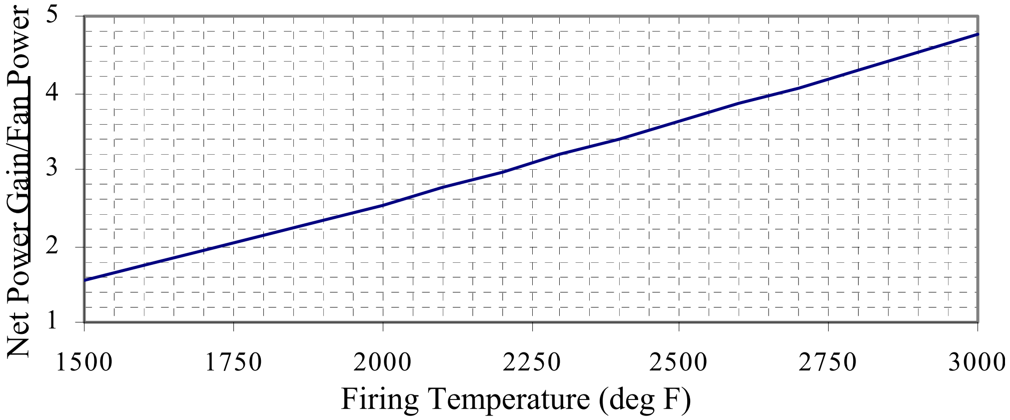

Figure 3 – Supercharging a gas turbine boosts power output in proportion to firing temperature. Graph assumes a 40 in. H_2O, fan-driven pressure increase, followed by fog cooling back to ambient temperature.