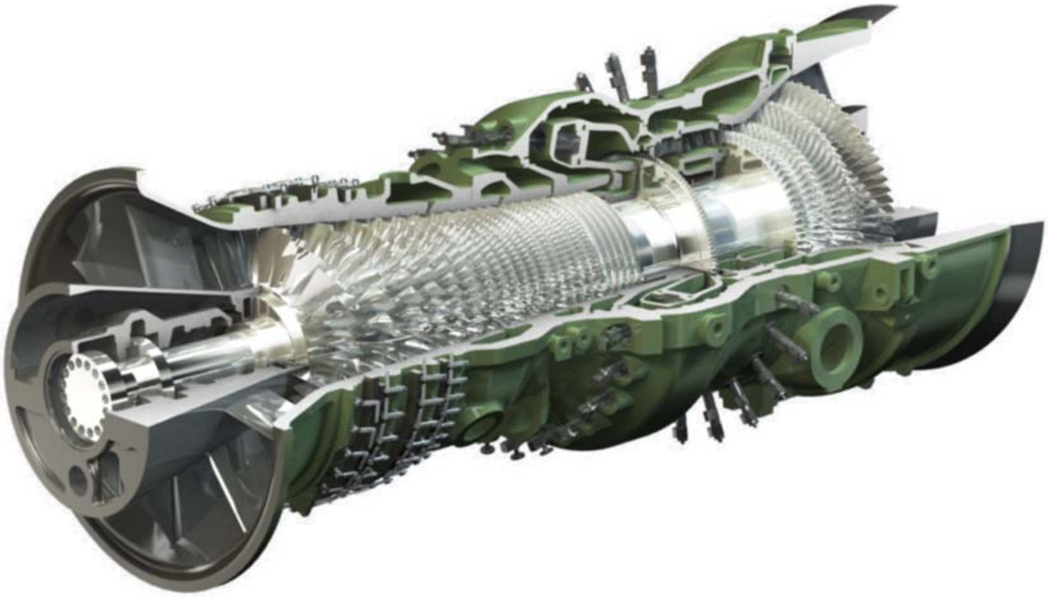
The Next Generation KA24/GT24
From Alstom,
The Pioneer In Operational Flexibility

Technical Paper



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The Next Generation KA24/GT24 From Alstom, The Pioneer In Operational Flexibility

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1 Introduction

In the recent years operators of a Combined Cycle Power Plant (CCPP) in the US power generation market have experienced the requirement for high operational flexibility due to changing electrical demand. Based on current forecasts, this trend for increased operational flexibility is expected to continue. While demand will continue to vary greatly, the growing portion of renewable sources of electricity production are expected to require combined cycle plants to be more and more used to levelize the overall production of electricity in many power market. As such, operational flexibility of gas turbines and combined cycle power plants is expected to play an even more important role in the US power generation market in the future.

For different demand conditions different optimization criteria have to be considered. During periods of high demand, operators want to maintain peak output reliably, whilst during off-peak periods combined cycle power plants are shut-down or operated at minimum stable load.

To meet these goals and market challenges, the next generation GT24 gas turbine, capable of delivering 230 MW at 40% efficiency (heat rate of 8’571 Btu/kWh), and the corresponding KA24 combined cycle power plant, which can achieve 700 MW output in a 2-on-1 configuration, has been developed by Alstom. This year the GT24 is celebrating it’s 15th Birthday since it’s introduction to the market in 1996. Since it’s early days this product was recognised for it’s exceptional operational flexibility, high part-load efficiency and fast start-up capabilities. From the very beginning this gas turbine technology incorporated features such as multiple variable compressor guide vanes and sequential combustion, which set a new industry standard regarding operational flexibility. Therefore Alstom is the pioneer in operational flexibility.

The paper describes in detail benefits which this next generation GT24 and the corresponding KA24 will provide to it’s users and operators. The unique features such as Low Load Operation (LLO), flexible operation modes and superior part-load efficiency are further explained in the view of techno-economic parameters. The major development steps of this upgrade, evolving from a platform, which accumulated more than 4 million fired hours and more than 50’000 starts, is detailed. In order to demonstrate the development targets prior to market introduction, a strict, in-depth validation program, following the Alstom Product Development Quality (PDQ) process has been performed. Alstom is ready now to offer this product, which can achieve more than 60% efficiency or a heat rate of less than 5’714 Btu/kWh.

2 Market Trends and Requirements

The US power market is driven by two fundamental factors: economics and environmental pressure. Building new power plants to meet future growing demand means also having to take into consideration more stringent global environmental standards. There is a great support for low carbon technology and renewables. Expected stringent environmental rules driven by EPA, lower natural gas prices (due to shale gas extraction), and state policies will result in another wave of gas power investments and significant expansion of wind and solar technology.

In addition to reducing capital costs, the increasing all-round efficiency is becoming one of the main market drivers for gas turbine and combined cycle development, so as to lower fuel consumption, and at the same time produce lower emissions (NOx, CO, CO_2, etc.) with the ultimate goal of having a reduction in the cost of electricity.

The shift in structural set-up from a regulated to a de-regulated power market resulted in the fact that many of the advanced gas-fired combined cycle power plants installed in the late 1990's and early 2000's were specified and designed based on base-load dispatch due to their relative high base-load efficiencies. The advent of the renewable power market has seen a dramatic shift in the role of gas-fired power plants, in particular combined cycle power plants. Today however, both existing and newly built combined cycle power plants are changing their typical operational profiles, moving towards heavy cycling and intermediate dispatch regimes. These gas-fired power plants are experiencing increasing periods of operation at part- and minimum stable load as well as frequent stop/starts (up to daily cycling). The impact of increased renewable power on grid networks is expected to see even greater need for combined-cycles to undertake a demand/supply balancing role, with increased periods operating at reduced or minimum load settings and/or actual shut-downs.

As today's markets require for most of the time operation in some kind of part-load or cycling regime, it is of high importance to consider a mixture of operational profiles in an assessment of competing plant technologies. To model the future most likely operation of a plant in a best way, weighting factors should be applied to possible operational profiles. Based on Alstom's experience of the KA24 fleet and its 50 Hz sister product, the KA26 fleet, with over 4 million fired hours, the base-load operation amounts to less than 25% of the overall operating profile. On the other hand we see plants mainly operating in the range of 60-95% plant load with some operation at part-loads as low as 40%.

Comparing the characteristics required by power generators from their combined cycles 5-10 years ago with those of today, a very different landscape appears. In the past the typical key customer CCPP specification requirements focused on:

- Highest base-load efficiency based on approx. 8000 operating hours per annum
- Lowest specific sales price ($/kW)
- Lowest overall operational costs
- Shortest delivery schedule
- Experience
- Low (NOx/CO) emissions at base-load

Due to the explained changes in the market, the specifications of today's CCPP must be based on:

- Highest overall weighted efficiency based on expected operating hours and load regime
- Lowest cost of electricity based on both, base- and part-load profiles
- Lowest overall operational costs based on the anticipated dispatching
- Reliability, availability and starting reliability
- Lowest minimum load during off-peak periods to minimize fuel consumption - 'parking mode'
- Longer intervals between inspections to lower operation & maintenance cots
- Start-up capabilities (particularly for hot / warm plant conditions)
- Loading / de-loading gradients & transient capabilities
- High cycling capability of all plant components
- Low emissions (NOx, CO, …) including CO2 over widest possible load range

We see that today's market is requesting many more requirements and capabilities compared with the past. The combined cycle power plant technology that is able to fulfill the most of the requirements above is the technology that is able to offer the highest operational flexibility. Such a solution will best suit the needs of a dynamic power market. This is even more so when keeping in mind that once the asset is bought and installed, it cannot be readily changed, at least not for many years.

3 The Next Generation GT24

Today we are celebrating the 15th Birthday of the GT24 gas turbine technology together with its 50 Hz version the GT26. Since it's introduction to the market in 1996, the advanced class GT24/GT26 gas turbines have demonstrated significant user's advantages of this technology platform. Unprecedented operational flexibility, superior part-load efficiency, low emissions over a wide load range with world-class levels of reliability and availability are characteristics of these gas turbines.

The main technology differentiator of Alstom's GT24/GT26 advanced-class gas turbines is the 'sequential (2-stage) combustion' principle (Figure 3.1). The GT24/GT26 combustion system is based on a well-proven Alstom combustion concept using the EV (**E**n**V**ironmental) burner in a first, annular combustor, followed by the high pressure (HP) turbine, SEV (**S**equential **E**n**V**ironmental) burners in the second, annular combustor, and the low pressure (LP) turbine. The dry low NOx EV-burner has a long operating history and is used in the whole Alstom gas turbine portfolio. Sequential combustion - 'the reheat principle for gas turbines' - had already been applied to earlier Alstom gas turbines by using two side-mounted silo combustors. Integrating the concept of dry low NOx EV-burner and sequential combustion into a single-shaft gas turbine resulted in the GT24/GT26 – an advanced-class (F-class) GT-technology with high power density and low emissions [1].

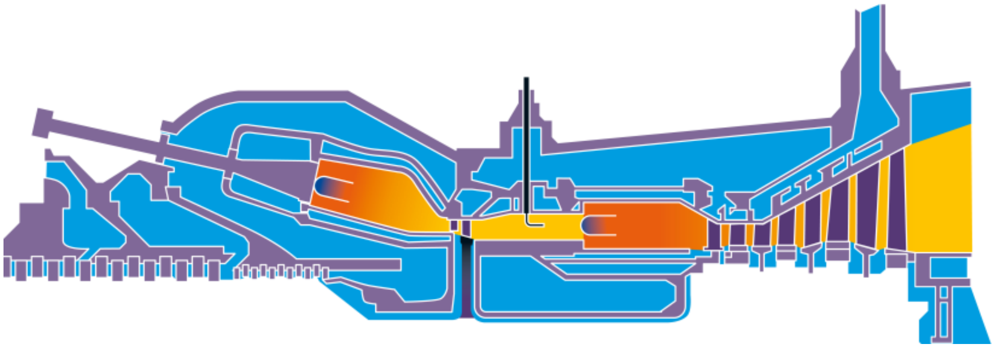


Figure 3.1: GT24 sequential combustion system

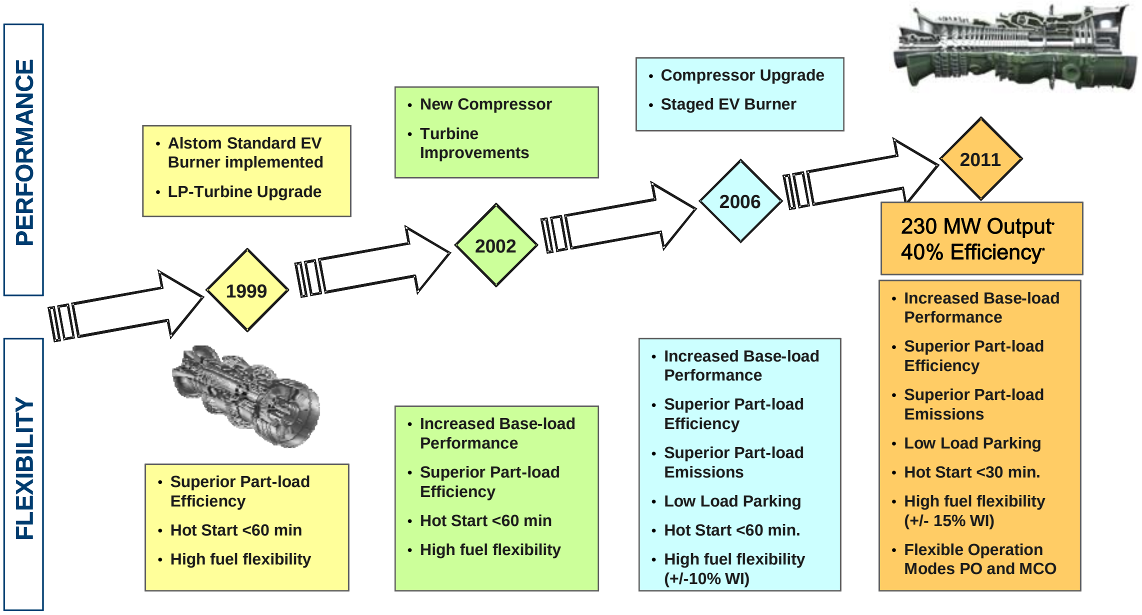
This sequential combustion combined with multiple variable compressor guide vanes. set a new industry standard regarding part-load efficiency and turn-down capability. These two main contributors to operational flexibility were already introduced by Alstom in the 90's, making Alstom the true pioneer of operational flexibility.

Since the first introduction of the GT24 gas turbine in 1996, there have been three upgrades (Figure 3.2):

1) In 1999, as part of the so called A-configuration to the B-configuration (Upgrade 1999)
2) In 2002, with the introduction of the first compressor redesign (Upgrade 2002)
3) In 2006, a rating increase with a second compressor upgrade together with a slight turbine inlet temperature increase (Upgrade 2006)

In 2002 the GT24/GT26 compressor was redesigned for an increased mass flow of approx. 5%, with the goal of having a similar increase in the combined cycle power output. This was achieved through both, optimized airfoil design and re-staggering of the compressor blades. The result was a design that required no change to the rotor and stator flow path contour. Compressor blade length and channel height, rotor and compressor vane fixation grooves, as well as blade and vane material all remained unchanged. Hence the design was retrofitable.

The next modification of the GT24 compressor took place in 2006. The compressor was re-staggered in the front stages to increase the mass flow further. Additionally, for optimization of efficiency and cooling air bleed conditions, some re-stagger was carried out in the high-pressure part of compressor. However, the actual flow path as defined by the outer casing and the rotor profile remained unchanged and this further upgrade is also fully retrofitable into the earlier engines. Besides the re-staggering, additional measures to optimize the compressor blade clearance have been introduced to increase the performance [2].



WI = Wobbe Index; PO = Performance Optimized;
MCO = Maintenance Cost Optimized

Figure 3.2: GT24 performance and flexibility evolution

Additionally, a stepped increase of the turbine inlet temperature for the LP turbine took place in order to improve the gas turbine engine and plant efficiency. This step could be taken based on good field experience with the GT24 and GT26 fleet in combination with additional hardware modifications concerning Thermal Barrier Coating (TBC) and cooling in the LP turbine.

For additional efficiency benefits the cooling and leakage air consumption has been optimized. Using the field experience and data obtained from the GT26 Test Power Plant in Switzerland, the cooling requirements in the SEV combustor could be adjusted to have an optimum between lifetime and efficiency. Meanwhile the upgrade 2006 front-runner has successfully achieved more than 35'000 fired hours of commercial experience.

Upgrade 2011 overview

Based on this continued development experience a further evolutionary step for upgrading the GT24 gas turbine has been achieved. The upgrade is utilizing the features of the latest GT26 upgrade [3], applying a scaling approach to the maximum extent. The latest evolutionary step further enhances the key benefits of this gas turbine and the associated KA24 combined cycle power plant. In specific this upgrade is designed for:

- Lower specific investment
- Superior operational flexibility:
    - Best-in-class part-load performance
    - Turn-down-capability down to 40% CCPP power and below
    - Two operation modes: maintenance cost and performance optimized operation mode
    - Increased robustness against natural gas composition variation
- Reduced emissions:
  Low NOx emissions at base load with a unique part load characteristic resulting in decreased NOx emissions at very low loads
- Low Load Operation ("LLO"), whereby the full CCPP can be parked at a significantly reduced minimum load point at below 20% plant load.

The next generation GT24 contains the well-proven EV combustor and HP turbine from the previous ratings without design changes. Evolutionary modifications are limited to the following components (see Figure 3.3):

- Compressor
  The modified compressor allows a further increase in mass-flow for higher engine performance at improved operational flexibility and high efficiency.
- SEV (2nd stage) combustor
  The SEV combustion system is improved for increased fuel flexibility at yet lower emissions
- Low Pressure (LP) Turbine
  The LP Turbine is optimized for high efficiency and allows for flexible operation at increased inspection intervals of up to 30%.

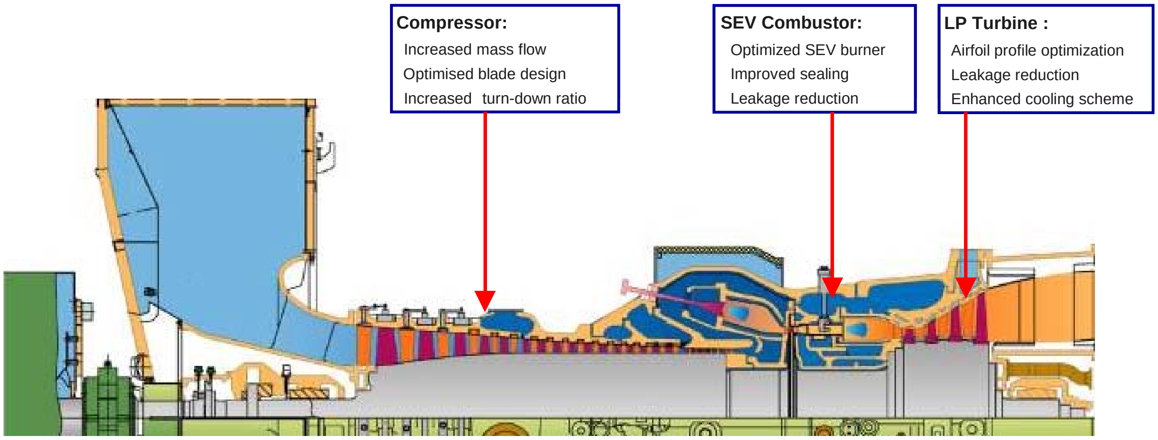


Figure 3.3: Overview of major areas of evolutionary design modifications

Compressor

The compressor upgrade results in an increased inlet mass-flow, and was designed for high efficiency over a wide ambient and load range. The architecture is based on the 22-stage well-proven Controlled Diffusion Airfoils (CDA) design as already used in the current GT24 engine. The outer annulus is increased to match the mass-flow increase. The compressor blading design was performed using tools developed by Rolls Royce, with whom Alstom has an unlimited technology sharing agreement. To increase the part-load performance even further, the variable vane row count has been increased from three to four. All upgrade design features are based on scaling of the latest GT26 upgrade compressor [3].

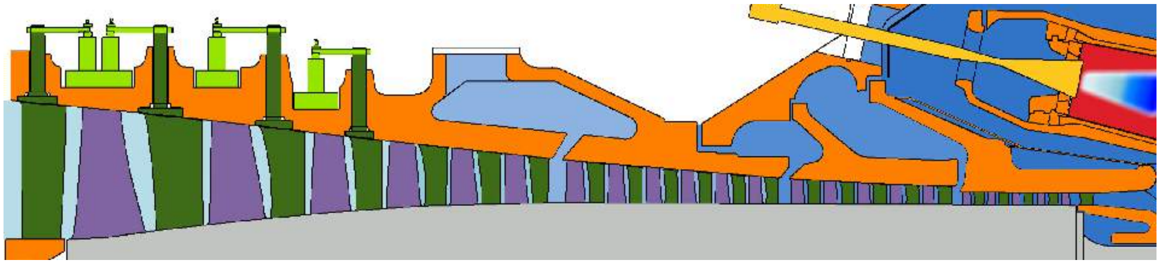


Figure 3.4: Compressor cross-section with four variable guide vanes

SEV Combustion System

The SEV combustion system architecture and structural parts remain unchanged to the current GT24. The SEV combustor upgrade is based on the latest GT26 upgrade concepts and features applying a scaling approach. The changes include a modified SEV burner, SEV fuel lance and fuel injection nozzle as well as improved seals to reduce leakages. The burner modifications ensure a better mixing of the fuel with the airflow resulting in lower emissions over a wide operation range. Additionally, the robustness of the SEV combustion system against fuel gas composition could be enhanced: fuel gas composition with up to 18 volume percent of higher hydrocarbons can be handled by the standard hardware, without fuel preheating or other fuel conditioning.

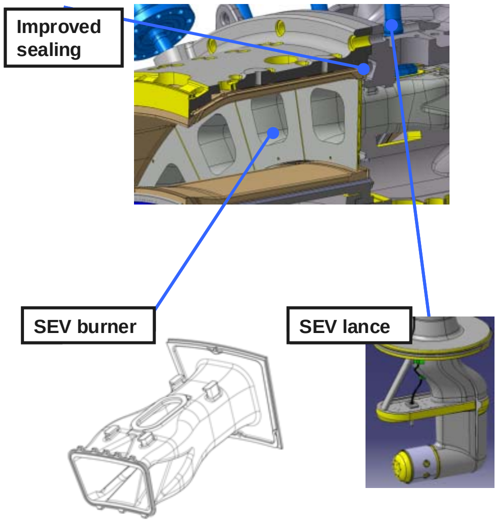


Figure 3.5: Modifications to the SEV combustion system

As with the earlier GT24 upgrades, the SEV combustion system will maintain its superior NO_x emissions characteristic with almost no additional contribution to the NOx emissions produced in the EV combustor. This results in a unique engine NO_x characteristic for the entire plant load range from 100% down to 40% and below (at the low load parking point at less than 20% CCPP load) – see Figure 3.6.

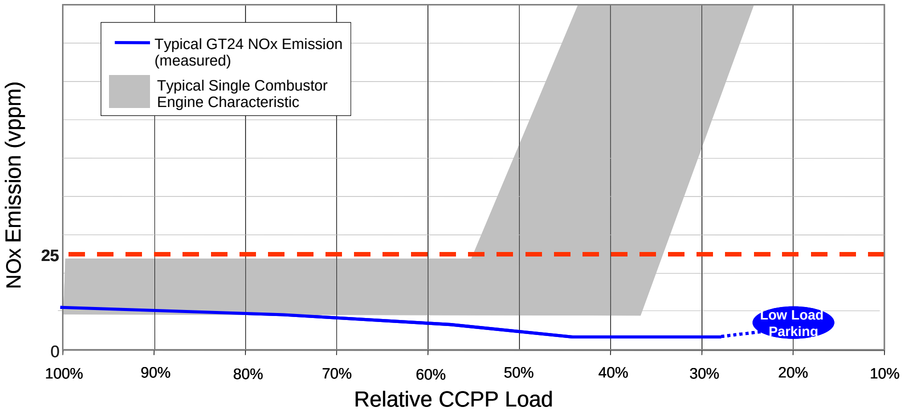


Figure 3.6: Unique GT24 NOx characteristic due to sequential combustion

Low Pressure Turbine

The upgrade package includes an improved LP turbine which is scaled from the latest GT26 upgrade to the maximum extent. The HP turbine remains unchanged. The benefits of the modified LP turbine are (i) higher component efficiency and (ii) the ability to switch on-line between two operation modes thereby enabling extended operation intervals between inspections of up to 30%. All four LP turbine stages contain airfoils with optimized profiles and cooling schemes. The blade shroud design was improved to reduce the over-tip leakages. In addition the vane-part count per row is reduced from the current GT24 to minimize the hot gas surface, which requires cooling. The turbine outlet annulus is increased to accommodate the higher inlet mass-flow delivered by the upgraded compressor.

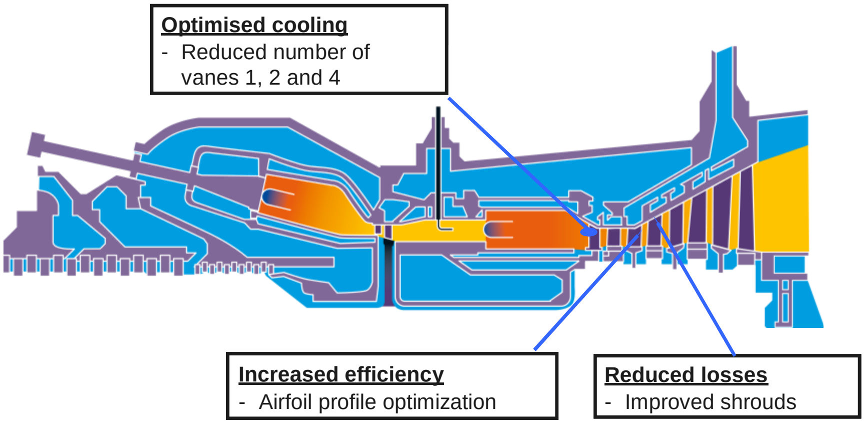


Figure 3.7: Modifications to the LP turbine

Figure 3.8 shows the vane and blade parts for stages 1 and 3. 3D airfoil profiling has been applied throughout all stages to achieve a high aerodynamic efficiency. As with the compressor, the turbine was designed using the Rolls Royce design tools under a technology sharing agreement.

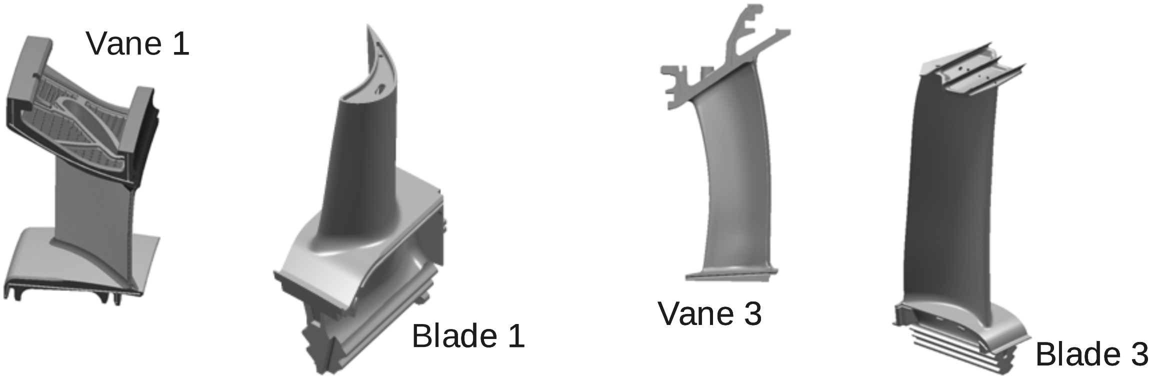


Figure 3.8: Turbine parts for stage 1 and stage 3 of the improved LP turbine

4 KA24 Plant Features and Benefits

Next Generation Performance

The Alstom KA24-2 combined cycle reference power plant is a 2-on-1 configuration, designed to be the leader not only in operational flexibility but also in all-round performance in it's class. For typical cooling tower and ISO ambient conditions, the KA24 is capable of delivering:

>660 MW net power output, >58% net efficiency

When fully optimized the KA24-2 has the capability to deliver:

- More than 700 MW gross output
- More than 60% gross efficiency
- Further increased part-load efficiency

This plant performance is based on the following GT performance data:

Fuel	Natural Gas	
Frequency	Hz	60
Gross electrical output	MW	230.7
Gross electrical efficiency (LHV)	%	40.0
Gross heat rate (LHV)	kJ/kWh Btu/kWh	9,000 8,531
Turbine speed	rpm	3,600
Compressor pressure ratio		35.4 : 1
Exhaust mass flow	kg/s lb/s	505 1,113
Exhaust gas temperature	°C °F	597 1,107

General Notes:
1. Gas turbine electric output and heat rate at the generator terminals including generator losses, but excluding inlet and outlet losses.
2. Gas turbine performance calculated with 100% methane (Lower Heating Value) ISO conditions.

Low Load Operation

Low Load Operation (LLO) is Alstom's unique feature stemming out of sequential combustion gas turbine. For customers operating in markets where daily stop/starts and/or parking at as low load as possible are required, the LLO feature offers additional flexibility. LLO allows operators to park the entire plant below 20% combined cycle power plant load with both GTs and the ST in operation. Compared to a 40-50% plant load, which is the current industry standard, the LLO feature provides a unique spinning reserve capability of the KA24-2, enabling to provide more than 450 MW additionally to the grid in 10 minutes without a risk of start failure and without cyclic lifetime consumption of the gas turbine.

Due to the sequential combustion technology the emissions at the LLO point stay at low levels ensuring that the plant complies with the most stringent single-digit emission regulations such as 2 ppm NOx, CO and NH3 slip. The LLO is achieved by switching off the second combustor (SEV), while the first combustor (EV) operates in its optimal point (thus producing base-load like emissions).

A simplified case study for the KA24-2 operating at the LLO operation point may demonstrate the economic benefits when compared to industry standard minimum stable operation at 50% plant load:

Main market parameters

Fuel Price ($/mmBtu)	**4.5**
CO2 Tax ($/Tonne)	**0**
Electricity price ($/MWh)	**45**

Expected operating regime

Operating hours / year	**4000**
Number of starts / year	**200**
Operating regime	**Cycling**

Typical Plant Capacity for Cooling Tower application on ISO ambient conditions

Net Output (MW)	**660**
Net Efficiency (%)	**58**
Net Heat Rate (Btu/kWh)	**5883**

For the above parameters, the difference in fuel consumed when the plant is operating at minimum stable load of 50% to that of a plant operating at below 20% assuming that this operation is applicable to approximately 650 hours a year, results in annual savings of M$ 1.6. Assuming a 20 years of plant life, present value of this feature amounts to M$ 17.8.

When compared to starts and stops, LLO provides plant operators the following benefits:

- Reduction of cyclic lifetime impact, thus benefitting on the maintenance cost side
- Faster re-loading when the power is demanded, allowing power companies to offer higher availabilities to grid operators
- Provision of a spinning reserve capacity able to meet rising load demands
- Avoidance of potential risk of start-up failures, which - depending on the dispatch prices - can have manifold negative impacts on the profitability (high liquidated damages and lost additional revenues, as well as losing priorities when dispatching due to unavailability).
- Reduction of cumulative emissions compared to parking a plant at a higher part load
- Avoidance of possible increased noise and water plume emissions possible during start-ups

Flexible operation modes

The next generation GT24 features Alstom's unique flexible operation modes, already available for the GT26 and for Alstom's conventional class gas turbine GT13E2. It allows with one set of hardware the on-line selection between a "maintenance cost optimized" operation mode with extended inspection intervals and a "performance optimized" operation mode for maximum output/efficiency to meet variable market requirements, while the plant is connected to the grid. The inspection interval criteria are shown in Figure 4.1: Compared with the Upgrade 2006 an increase of around 30% can be achieved, resulting in a corresponding increased availability and reduced maintenance cost.

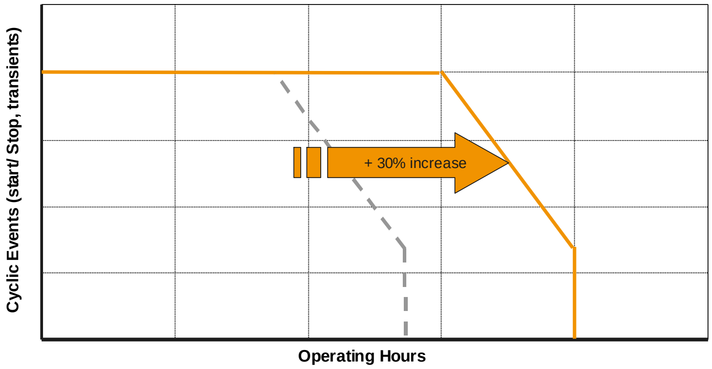
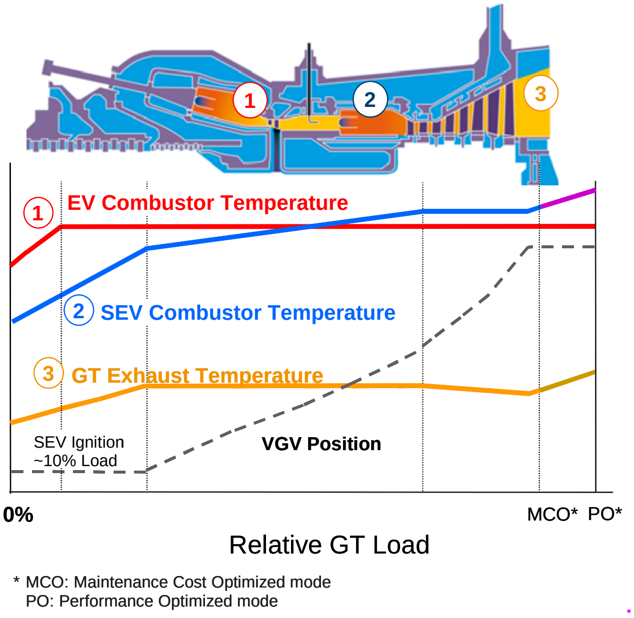


Figure 4.1: Longer inspection intervals with the next generation GT24

The operator has the option to run during high part load operation in the performance optimized mode. In this mode the firing temperature is increased – as a result a higher exhaust gas temperature is achieved for better combined-cycle performance. In the maintenance cost optimized mode, the firing- and the exhaust-temperature are lower, resulting in a small reduction in performance. Hence the interval between the GT24 inspections is extended by up to 30% and can achieve 4.5 years for a hot gas path inspection. This on-line switchable feature offers a further increase in the degree of operational flexibility delivered by the GT24 and the corresponding KA24 combined cycle power plant**.**

Sequential combustion operation concept



* MCO: Maintenance Cost Optimized mode
PO: Performance Optimized mode

Figure 4.2: Operation concept

Sequential combustion results in a unique operational flexibility. This is becoming clear when looking on the GT24 operation concept (Figure 4.2): After ignition of the first combustion chamber the firing temperature reaches at around 10% relative GT load already it's design value and stays virtually constant till base-load, thus providing optimal conditions for low NOx emissions over a wide load range

The second combustor is ignited by self-ignition due to already high inlet temperature at around 10% relative GT load. The GT loading is then performed by increasing the firing temperature in the SEV combustor together with opening of the VGV's to increase the air inlet mass flow. This is done in such a way that the GT exhaust temperature stays nearly constant over a wide load range, thus enabling the high plant part load efficiency and reducing the thermal stresses of the HRSG in case of load balancing operation.

Sequential combustion can be therefore considered as a mean of separating the emission production, which is mainly done in the first combustor, from the power generation, which is mainly done through the second combustor. This results in unique benefits:

- Highest part-load efficiency and thus lowest CO_2 production
- Highest turn-down capability of the entire plant
- Unique NOx emission characteristics with NOx decrease when de-loading

Part Load Behavior

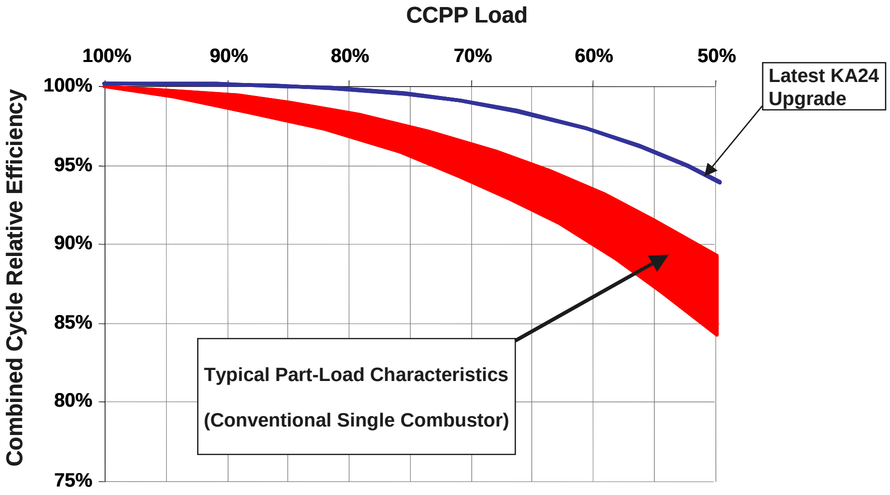


Figure 4.3: KA24 Part-load characteristics

The result of the above described operation concept is a superior part-load efficiency characteristics of the KA24 CCPP. One distinct characteristic is the fact that the plant efficiency stays nearly constant from 100% down to 80% combined cycle, a capability unique in the market.

Further analysis of the case study as defined in the LLO section above is performed for the part-load characteristics as shown in Figure 4.3. For the cycling operating regime (4'000 OH / Year, 200 starts, 60% of the time operation at part-loads between 60 and 95%) annual savings of fuel when compared to typical single combustor part load characteristic exceed 6'500 tones per year. At the fuel cost of 4.5 $/mmBtu, annual savings are close to M$ 1.5, and if discounted over 20 years of plant life, this can amount to as much as more than M$ 15 of present value. As the economical impact of the part load performance is significant, the additional effort to perform a careful evaluation of various load profiles in addition to the base-load is certainly worth the effort. Additionally, as more than 18'000 tones of CO_2 can also be avoided, in a likely case of future regulations introducing a CO_2 tax, even higher economic impact can be expected.

Spinning Reserve, Fast Starts

Besides superior part-load performance, Alstom's KA24 has been designed to ensure that grid electricity supply can be maintained, should there be an unexpected loss of generating capacity. With the LLO feature the KA24 provides a unique operational spinning reserve capacity by being able to deliver more than 450 MW additionally within 10 minutes, as illustrated in the Figure 4.4.

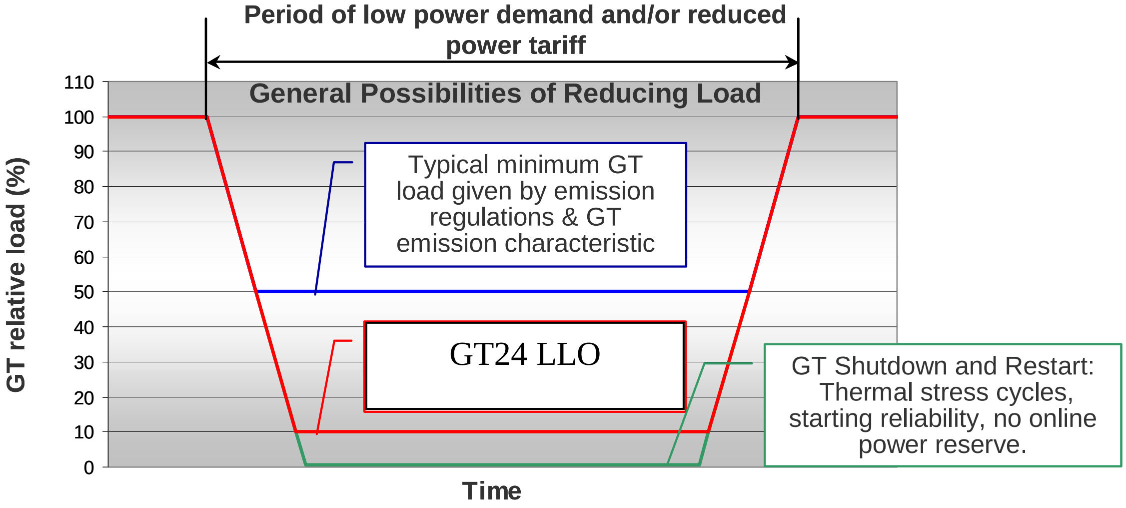


Figure 4.4: Ramp up from LLO to base-load – 10 minutes spinning reserve

Fast start-up times are achieved through careful identification and design of all plant components. Hot start-up times of 30 minutes are possible without lifetime implications on any of the plant rotating equipment as well as steam generators.

5 Technology Validation for Reliable Plants

5.1 Alstom's F-class Operational records

In the power industry, it is important for any operator to focus not only on the operating hours experience but also to understand if the entire plant technology is fit for various operational scenario i.e. from peaking over cycling and intermediate operation to base-load. Variations are expected to be seasonal and regional and very difficult to predict. Only those combined cycle power plants are said to be successful today in the market if it successfully demonstrates that all types of duty cycle operation can be met without constraints.

The KA24/KA26 combined cycle power plants are already providing such flexibility. Figure 5.1 shows the operating characteristics during the past 5 years for KA24/KA26 demonstrating that these Alstom's F-class reference power plants are best suited for the full range of operating regimes.

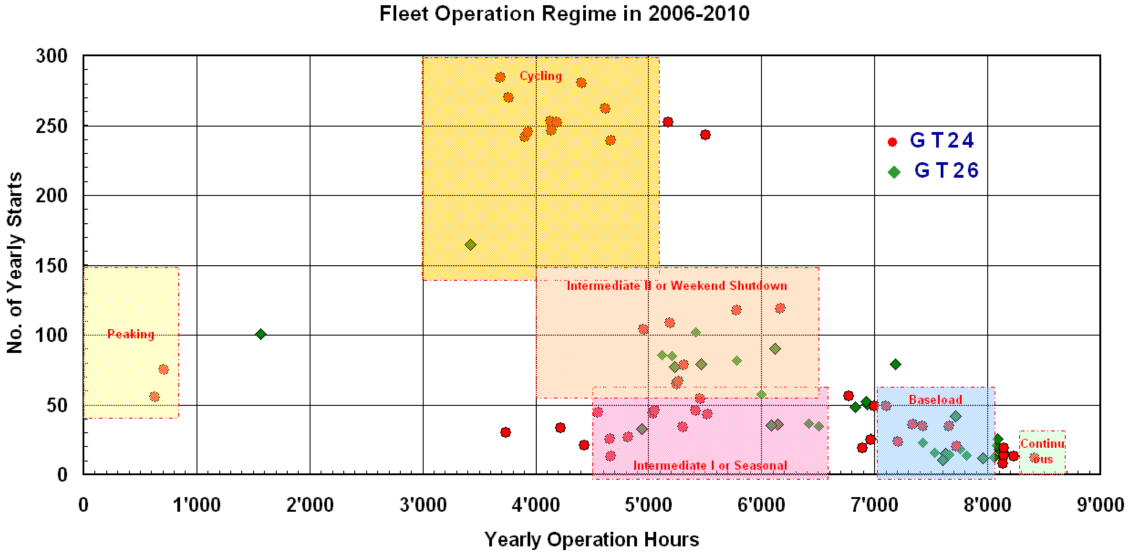


Figure 5.1: Average KA24 / KA26 fleet operating regime (2006-10)

The GT24/GT26 fleet has now achieved more than 4 million fired operating hours with more than 70'000 starts. The GT24 fleet itself has accumulated more than 2.3 million fired hours with more than 50'000 starts. Significant experience has been gained with conventional base-load operation, but also with intermediate cycling and daily start and stop operation. The GT24 and the KA24 combined cycle power plant have demonstrated its flexibility and reliable start-up characteristics.

5.2 Next Generation GT24 Validation

Validation Strategy

In order to ensure validated and highly reliable products Alstom is using a gated Product Development Quality (PDQ) process. This process defines at a very early stage during the design phase for each component, the appropriate validation measure to reduce risk to a minimum level. The PDQ process has been applied for the next generation GT24/GT26 with regard to the validation of tools, parts, components and complete engine. For each component various validation steps have been performed such as design feature validation (to validate the cooling channel design), component validation, full engine validation in the Alstom GT26 Test Power Plant and field monitoring. In general, as the GT24 upgrade is based on scaling from the latest GT26 upgrade to the maximum extent, the results from GT26 engine validation can be read across.

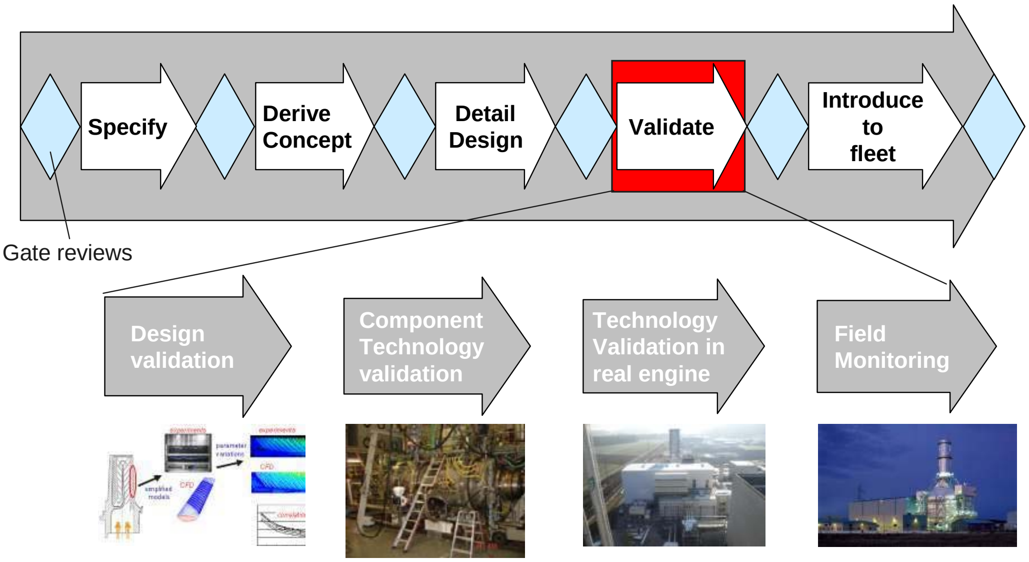


Figure 5.2: Validation steps according to Alstom's PDQ process

Technology validation in real engine

The full upgrade package has been implemented in the GT26 Test Power Plant in Birr, Switzerland. A dedicated test campaign started in 2011 and after successful validation enabled market introduction of the next generation GT24/GT26.

The Alstom Test Power Plant is connected to the Swiss grid. It is dedicated for upfront testing of upgrades in all kinds of operation regimes, i.e. from base-load to extreme off-design conditions, before products are released to the market.

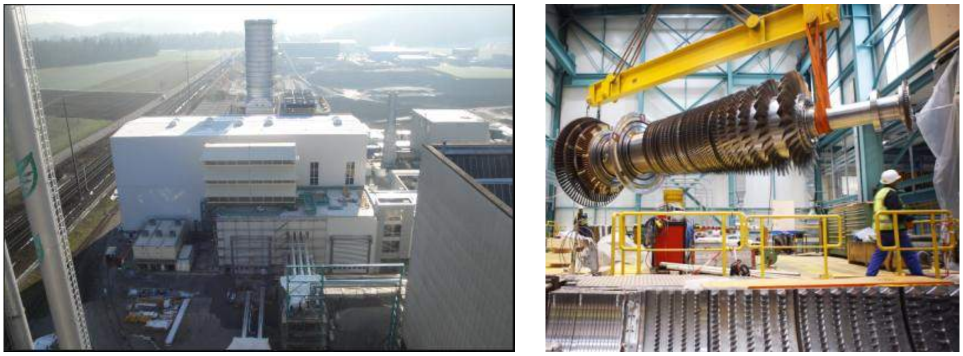


Figure 5.3: GT26 Test Power Plant

Special instrumentation techniques applied are shown in Figure 5.4. For this test and validation campaign, Alstom has installed more than 4'000 additional test-instrumentation above standard to ensure maximum engine performance monitoring under all operating conditions.

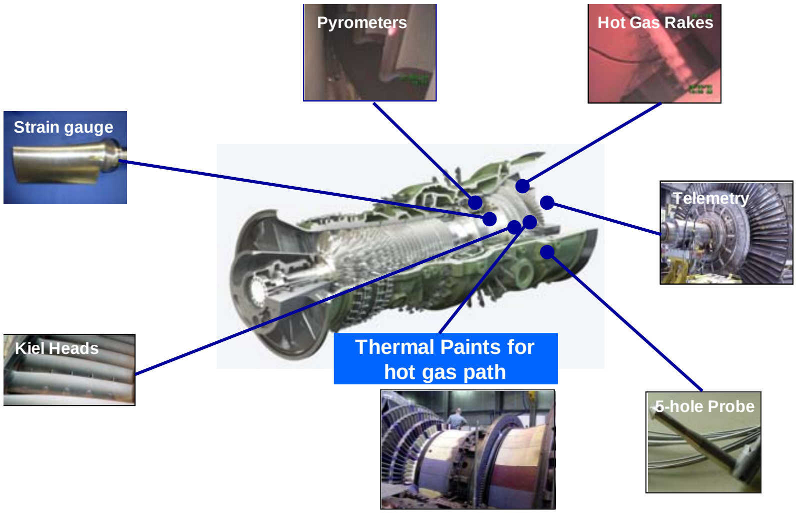


Figure 5.4: Special instrumentation overview for GT Test Power Plant

Turbine validation

The turbine technology validation was done in three-steps. As a first-step, the turbine internal cooling schemes and their internal heat transfer was validated in an in-house test facility using Perspex models and thermo-sensitive liquid crystal measurement technique (Figure 5.5).

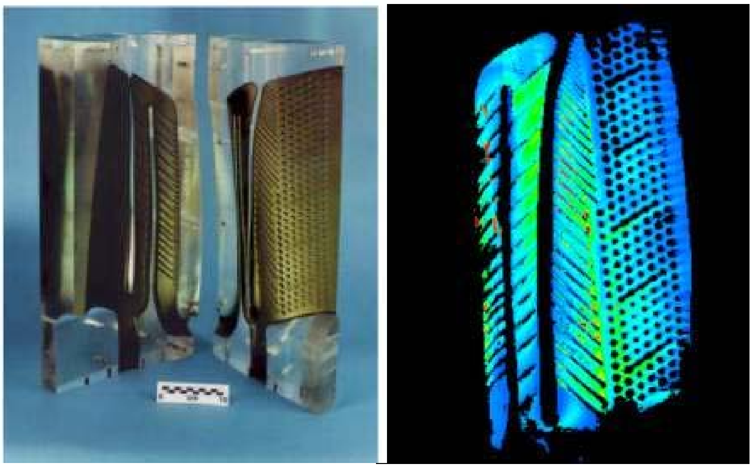


Figure 5.5: Internal heat transfer validation using thermo-sensitive liquid crystals and Perspex models

The second-step of turbine component validation was done during two engine test campaigns in the GT26 Test Power Plant. The first test campaign was a dedicated thermal paint run for the improved hot gas parts (Figure 5.6). The second campaign was a performance and mapping test campaign to validate the LP Turbine performance characteristic over the entire range of operating conditions.

Figure 5.6: GT26 test power plant - thermal paint test of the LP Turbine

Based on the good results from the tests in the Test Power Plant, the LP turbine hardware was released for a front-runner operation in a commercial KA26 unit in Spain. Performance guarantees were exceeded. This front-runner saw its first scheduled borescope inspection in September 2010 at 5'529 OH, 45 starts. As Figure 5.7 shows the LP turbine has been in excellent condition. As of September 2011 the turbine has accumulated more than 8'000 OH.

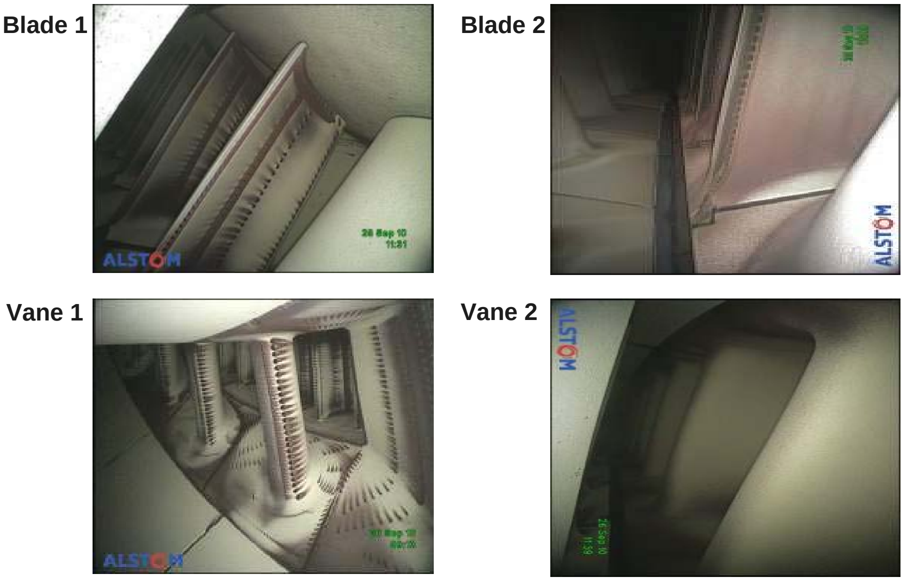


Figure 5.7: LP turbine frontrunner borescope inspection

Compressor validation

The compressor validation was done in a two step approach. Fist step being tests in a scaled rig and second step was full engine validation in the GT26 Test Power Plant. During the mapping of a GT compressor when the engine is connected to the grid, the operating line from idle to full load can be validated. In order to gain a full compressor map over the entire speed, ambient temperature and pressure ratio range a full 22-stage scaled-rig was built and tested. The scaled-rig included bleed slots and inlet and outlet geometry and all variable rows as the full-scale GT24. On top of compressor mappings, upfront start-up optimizations for start-up power and time were undertaken. The mapping of the compressor was carried out up to the surge limit, far beyond the GT24 operating line requirements. The rig is one of the world largest axial compressor rigs for pressure ratios above 30. The instrumentation scope for the rig includes pressure taps throughout the compressor, both steady and transient temperature measurements, strain gauges, tip timing and clearance measurements.

SEV Burner validation

The SEV Burner validation was done in a two-step approach. The first step was to carry out a single burner test in atmospheric and high-pressure rigs. The single burner high-pressure test rig is used to measure and analyze the mixing and emission behavior, to check the flame stability limits and the acoustic behavior. Parameter variations are done for inlet and outlet boundary conditions, and in particular for various fuel types (varying heating values and higher hydrocarbons content). The instrumentation on the rig contains more than 500 measurement locations for temperatures, pressures, acoustics, emissions and flame positioning. Out of the single burner test rig different burner fuel lance configurations were selected for full-engine tests in the Alstom Test Power Plant at Birr in Switzerland. In a test series the best configuration was selected for implementation. This configuration was then mapped for the full operating concept and a large ambient range.

6 Retrofit Packages

Alstom ensures that the improvements to the GT24/GT26 platform can be offered as retrofit packages wherever possible. In this respect the LP turbine of the next generation GT24/GT26 is offered as an upgrade.

The first LP turbine was already retrofitted in the GT26 unit Castejon in Spain. As reported by the plant owner HC Energía, this retrofit package helped to even further improve the competitiveness of the asset, by enabling even higher operational flexibility, with improved performance and additionally extended intervals between inspections (1).

The GT24 turbine retrofit package enables an extension of the hot gas path inspection intervals by up to 8’000 operating hours while simultaneously increasing the output by more than 13 MW and decreasing the heat rate by more than 88 Btu/kWh in performance optimized operation mode, which corresponds to + 5 MW and −40 Btu/kWh in the maintenance cost optimized operation mode. As the result of the extended interval between the hot gas path inspections, maintenance costs can be reduced and in combination with the improved performance, the overall plant economics improve. The actual performance improvement values are subject to specific configuration of the GT24 and it’s plant components.

7 Summary

Alstom's position as the pioneer in operational flexibility continues. The outcome of this next generation GT24 is a proven advanced-class gas turbine technology, with the best-in-class all-round performance to further increase the competitiveness for power plant operators. Moreover, the commonly known strengths of the GT24 – long recognized and appreciated for its high all-round operational flexibility and the high fuel flexibility – have been further extended. The benefits for operators of the next generation KA24-2 are:

- More than 700 MW gross when fully optimized
- More than 60% gross efficiency
- The best-in-class part-load efficiency
- Increased inspection intervals resulting in higher availability
- Reduced maintenance costs of up to 30%
- Switchable (on-line) operation modes to adjust the gas turbine performance according to market requirements and thereby offering better inspection planning
- Low Load Operation for parking the entire combined-cycle power plant at less than 20% CCPP load and still meet the emission requirements
- A spinning reserve for delivering more than additional 450 MW in 10 minutes from Low Load to Base-load.
- Fast hot start-up times of 30 minutes

Alstom's development philosophy is to attain the balance between providing advanced technology while maintaining the proven levels of high availability and reliability based on an evolutionary approach. The latest upgrade of the GT24 is a perfect example for this approach. Based on the basis of a well-proven gas turbine, Alstom has further developed the Compressor, the SEV Combustor and the LP turbine while keeping the EV combustor and HP turbine unchanged.

Validation is a key step within Alstom's development process - for the latest upgrade the validation has been performed to the maximum extent on the 50 Hz version, the GT26 engine, with results being transferable to the GT24 engine:

- Technology validation under real engine conditions in the Alstom GT26 Test Power Plant in Switzerland
- Full testing of Compressor, SEV Combustor and LP turbine in various test rigs
- Validation of the LP turbine technology, operating commercially in a retrofitted unit for more than 8'000 operation hours

8 References

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