REPORT ON THE FIRST OPERATIONAL EXPERIENCE OF THE NEWLY COMMERCIALIZED 29MW SGT-700 (GT10C) GAS TURBINE

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0. Abstract
During the past year Siemens’ recently launched 29MW SGT-700 gas turbine has been proven in commercial operation and is showing great progress as a new product. The turbine is in commercial operation in a number of different applications at three site locations and a fourth site is in the rotating commissioning phase. Applications cover mechanical drive, power generation, offshore and onshore, and the turbines operate on both single and dual fuel.

In total, seven units have been delivered of which six are in commercial operation. The first 25 000 hours of erection, commissioning and commercial operation have passed without major findings for our customers. Operation has been affected only by minor outages. Actions have been performed with a speedy and effective response to cause minimum disturbance to the customer.

1. Market Introduction
The product release has moved on to an intensive phase to meet the market demands for reliable and mature design. The past years of extensive validation of the product have proven to be a good investment. The concept is based on the two-shaft unit but with third-generation DLE (Dry Low Emissions) combustion technology. The robust design from the SGT-600 (which has accumulated over three million operation hours) is utilized to maintain high availability and reliability and has been an excellent platform for the SGT-700 introduction.

In November 2001 the first engine was started and passed through the first part of the validation process. Complete disassembly and visual inspection of each component were standard procedure during this first year to validate the design. Clearance and dimensional checks were performed to verify the design. During disassembly/assembly our tools and working routines were also validated. We also took the opportunity to improve the maintenance routines and to highlight important assembly steps.
Focus during the past year has changed from an intensive quality assurance of the internal engineering to an external focus on the customer and his application, concentrating mainly on raising availability and reliability. The introduction program has shown the importance of being on site close to the customer to give support and listen to his voice. The units (gas generator with power turbine) are standby and have been updated with the latest design features. Fast response has been essential in order to meet availability/reliability requirements even in an emergency situation. None has been used in commercial operation.

Main activities have been
- Resident engineering support on site and reporting a trained eye’s observation
• Inspections at intervals of 2500 operating hours. Currently three inspections have been performed (2x2500, 5000 hrs).
• Continuous updating of back-up plans such as preventive, operational and emergency spares.
• Review of feedback from sites and identification of potential improvements for other sites.
• FMEA – (Failure Mode and Effect Analysis) has been used for judging new and potential findings that affect our customer.

Our Condition Monitoring System (CMS) has been an important tool for the engineering team to investigate root causes on reported findings from site. The system permits on-line evaluation direct from site.

2. Design features
• SGT-700 has an increased airflow (from 80 to 91 kg/s compared to the SGT-600, by extending the compressor blading profile and introducing one additional compressor stage).
• A different combustion system has been introduced (same as the 45 MW SGT-800), which represents the third generation of DLE demonstrating 15ppm NOx on gaseous fuel and 42 ppm NOx on liquid fuel without any introduction of water or steam.
• The turbine inlet temperature (TIT) has increased by a moderate 27°C (from 1115° to 1142°C, mixture temperature according to ISO). The compressor turbine has a modified cooling design in order to handle the increased TIT.
• The pressure ratio has been increased from 14 to 18.
• The power turbine has been designed for a lower speed (from 7700 rpm to 6500) in order to better fit the mechanical drive market. Since speed was reduced and output increased, the turbine now has a larger diameter.
• The efficiency has increased from 34 to 37%.
3. Design verification

In late 2001 the verification tests were initiated and the turbine underwent a number of different development stages in the test facility in Finspong, Sweden, being tested for different purposes. During these tests 1200 additional measuring points were installed. Initial tests verified good respect to blading frequencies and cooling/sealing air temperatures. The next step focused on combustion in the whole load range to maintain low emission independent of operation.

The test facility was extended with a small gas plant to evaporate liquefied natural gas (in order to be able to run on gaseous fuel). The liquid fuel system already existed at the facility. The test bed is built as a normal single lift (as for production units) to validate the performance of auxiliaries. GT enclosure, inlet and exhaust duct are as a normal production delivery. Load is created by putting 50/50 to grid and load resistors. The driven unit is an air-cooled generator which is a normal production unit. Part/full load, transient, load rejection, instant load and a wide power turbine (PT) speed range can be tested (50-105% PT speed) at the extended facility in Finspong, Sweden. The conditions fulfill normal behavior for power plant or mechanical drive.

The control system and the operator monitoring of the test bed is set up as for Siemens deliveries, although additionally equipped with relevant data acquisition systems during validation. During the testing phase, various needs (blade dynamics, pressure, temperatures etc) were given by the engineering teams in order to validate the design.

Detailed mapping of the compressor and turbine was then performed by two spectacular tests. First was a full scale surge test of the compressor to define the surge line over the whole load range. The test was performed in the test bed with support from the normal auxiliary systems (lubrication oil, fuel etc.) but excluding the power turbine, the rotor and the eleventh stage of the compressor. The engine was equipped with an inlet throttle and water injection in the exhaust to
be able to manage the full scale conditions. Fuel (oil) was supplied instantly to force the compressor into surge and this occurred without a trip. Then the speed could be altered directly (in steps) to map the whole speed range (7,000-10,000 rpm). Data acquisition was adapted to meet the requirement for fast logging. Instant fuel gives fast transient changes of speed and pressure, which set the conditions for the system.

*Picture 2a and b: Surge test of the compressor – inlet throttle in front of compressor inlet*

Then, at the beginning of 2003, a full engine test was made to verify cooling efficiency of the turbine and air temperature profile. A total number of 650 measuring points on the turbine blading (blades, vanes and heat shields) gave valuable information on the cooling and essential information for fatigue analysis/life prediction. This measurement was made by installing crystals, using a thermo-cement technique to glue the crystals into holes (Ø 0.5mm). The gas path temperatures were measured by placing crystals on extended ceramic pins attached to the leading edge of rotating blades and stationary vanes. The crystals were exposed only during a 10 minute full load test. Telemetry (for measure blade temperature) and thermo paint was used as a reference for the crystal (see picture 2).

*Picture 3: Thermo paint showing isotherm line on exposed compressor turbine blade.*

Currently and during the past year focus has been on customer support and working preventively to ensure high availability. An extended inspection program is running (see below) to secure
stable and reliable operation. Historic findings are carefully followed and investigated to verify our long-term goals.

4. Delivered units and different applications around the globe
Seven units with a variety of applications are installed in four different sites and these have accumulated a wide range of experience. During the second half of 2004 numerous verifying tests were performed to tune the process and thus secure the stability of the power plants and production units. Units for power generation, mechanical drive, both gas-only and dual-fuel, have been in commercial operation since late 2004. Six units went into commercial operation within a few months and all have met our customer’s expectations. The following descriptions of each site application and purpose show the broad capacity of SGT-700. To work from the “platform” of SGT-600 has reinforced the availability/reliability benefits for the SGT-700.

Port Said Project, Egypt
Two identical trains for the United Gas Derivatives Company (UGDC) in Egypt were ordered in November 2002 for delivery to a natural gas liquids (NGL) plant in Port Said, Egypt, owned by UGDC, a special-purpose company owned in equal parts by the Oil & Gas majors AGIP, BP Egypt and GASCO. Before delivery from the workshop, the package (including driven compressor – also of Siemens manufacture) was string-tested in Finspong, Sweden. The plant is at sea level and its mechanical design is for an ambient temperature of 45°C. All equipment and instrumentation is protected against the highly corrosive marine climate by tropicalization of electric components. Because of the nature of the plant, environmental, health and safety considerations are paramount in all aspects of the site work. Installation is complete, and commissioning began in the summer of 2004. Both turbine-compressor sets have been in commercial operation since the end of 2004 and deliver according to committed contracts.

4.1 The UGDC Port Said Nile Gas project (2xSGT-700, mechanical drive, gaseous fuel).

Sochi Project, Russia
The first two SGT-700 gensets have been delivered to JSC City Energo, Moscow, for the end customer RAO UESR (Unified Energy System of Russia), and are now installed in a new
76MW combined heat and power plant which provides power generation and district heating for the town of Sochi, Russia's major resort on the Black Sea Coast. To ensure continuous operation the units are equipped with dual fuel technology (liquid fuel operation as back-up). This shows the importance of availability/reliability for the customer.

4.2 The Sochi project (2xSGT-700, power generation, dual fuel)

Eischleben Project, Germany

In December 2003 Siemens received an order from Wingas for two SGT-700 compressor trains for a pipeline compressor station in Eischleben, near Erfurt in Germany. This station is the terminus in Germany of the Yamal pipeline, which originates in the Yamal peninsula in Siberia, and travels through Belarus and Poland to Germany. From Eischleben the gas is distributed further to Germany and Western Europe through existing pipeline channels.

4.3 The Eischleben project (2xSGT-700, mechanical drive, gaseous fuel)
4.4 The Oxy project (1xSGT-700, mechanical drive, gaseous fuel, offshore installation)

5. Commercial operation statistics

As of October 2005 approx. 28,000 running hours have been accumulated with six units in operation, the fleet leader being at approx. 7000 operation hours. The total number of starts is around 200, where the fleet leader has some 40 starts in commercial operation. Main experience is based on four units which now been in commercial operation (GT handed over to customer) since Dec 2004 and totally 11 calendar months. Two more units went into operation in May 2005.

Measures (reliability/availability) are based on the Siemens delivery which includes both gas turbine and auxiliaries. Reliability is based on unplanned outages and availability on planned/unplanned.

Availability and reliability are prioritized and essential for our customer because units are integrated in a larger infrastructure (pipeline or process). AT the beginning of 2005 the plants were tuning the process to optimize the production and during the year operation has been on 80-85% load for mechanical drive application (four units) and 100% load for power generation (two units).

The reliability factor during the first year or operation (Dec 2004-Oct 2005) is 98.9% and the corresponding availability figure is 97.7%. These figures are the average of the fleet of four units from the first day of commercial operation. The facts behind these figures are described in the chapter below.
Two factors are not shown in the summary, the commissioning of back-up fuel (diesel) in Sochi and initial disturbance with the safeguard system in Port Said. These options are not representative for the introduction of SGT-700. Reliability and availability are reduced to 98.5% and 95.7% if they are included.

6. Operation disturbances

6.1 Forced outage (unreliability)

Picture 6: Unplanned stop contribution (bar) and accumulated percentage (line)

Gas hoses damaged (69% of the total unreliability)
Fuel changeover in Sochi has caused damaged fuel hoses and root cause is stated as HCF (High Cycle Fatigue) during this sequence. New design of fuel pipe has been implemented.

Control system (12% of the total unreliability)
GT tripped on Loss of Excitation due to disturbance on Electrical grid in Sochi. Start motor failure led to barring blocked for 10hrs.

Oil motor failure (6% of the total unreliability)
A motor broke down in the oil mist fan in Sochi and is a single fault on one unit.

Electrical equipment (5% of the total unreliability)
Different minor faults in electrical equipment and the electrical installation.

Other #1-#9
Minor outages have been detected but limited to a few percentages.
6.2 Planned outage (unavailability)

**Picture 7: Planned stop contribution (bar) and accumulated percentage (line)**

Inspection of turbine & flow test burners (48% of total unavailability)
Additional inspection has been a part of the introduction program for SGT-700. Selected components were disassembled for thorough investigations (spark plug, fuel injectors (burners) etc) which were essential for risk assessment.

Installation/Dismounting of Performance test equipment (27% + 11% = 38% of total unavailability)
After commissioning of back-up fuel (diesel) each unit passed the performance verification and the customer acceptance criteria.

Installation of pulsation governing equipment (6% of total unavailability)
The introduction program for SGT-700 has focused on issues for outages and combustion is an identified area. All units have been updated with the system to secure reliable operation for our customers and fulfillment of lifetime predictions. All new units have pulsation governing system and alarm set on a safe level for reliable operation.

Normal stop (5% of total unavailability)
Normal stops caused by different reasons (e.g. compressor washing to improve performance).

Other
Minor outages have been detected but limited to a few percentages.
7. Operation disturbances – conclusion
As shown above, the main contributions to the unavailability and unreliability are related to non-
standard delivery or extended scope. If these outages are excluded (Control/safeguard system,
commissioning/back-up fuel) the corrected figures would be 98.9% reliability and 97.7%
availability. The extended inspection interval has also lowered the numbers slightly, but was
necessary as part of the introduction program for SGT-700. An issue was found which extended
this planned inspection (see chapter 8.3).
Frequent stops are always causing interruption for the customer in his process and loss of
production, albeit only for a few hours. A measure of this is MSTFO (Mean Service Time to
Forced Outage) which has been improving over the year. Several minor stops at the beginning of
the year are still included in statistics. Currently (Oct 2005) MSTFO is approx. 700 operation
hours and continuously improved over the year..
The combustion system has shown good durability over time with stable emission levels under
normal operation conditions (start-stop, transients, fuel etc). Emission levels were set once in
accordance with contractual agreements (with margin) and have not required additional tuning
over the year.

8. Inspections
During its introduction, the SGT-700 was subjected to extended inspections on sites in close
cooperation with our customers. Three additional first level inspections have been performed so
far to follow earlier findings and highlight new. Two inspections at 2500 hours and one at 5000
hours show findings in line with our expectations. A few unexpected findings are described
below and also shown in chapter 6.
The first level inspections are/were planned to be made after approx 2500, 5000 and 15 000 EOH
(equivalent operating hours) on the fleet leading engines. These involve a boroscope inspection
of the hot sections of the engine and the rotating parts in the compressor (see picture below). It
also includes a visual inspection and function check of parts that are easily available for
inspection from the outside (VGV system, Bleed valves, Fuel injectors, Igniters, Flame detectors,
By-pass valves etc). Some additional disassembly has been made (when time was given) to
check critical components (i.e. spark plug, flame detectors, valves, fuel injectors, turbine
blading).
An extended disassembly and inspection is also planned to be carried out after 10 000 EOH for at least the fleet leading engine (early 2006). This will involve a full inspection of all internal parts including destructive testing and life estimation analyses of turbine blading in the laboratory in Finspong, Sweden.

8.3 Inspections performed and their findings

The first level inspections have been performed after approximately 2500 EOH on Port Said unit 2 and Sochi unit 2. Two remarks were reported, the first being an indication on one turbine stage 2 blade in the Port Said unit 2. This blade was removed, cut and examined by microscope in the laboratory in Finspong. The indication turned out to be no more than an artefact on the blade surface. The other remark was also on Port Said unit 2 and was related to an abnormal amount of debris inside the engine. The inlet filter was inspected and corrected to seal off suspected leakages.
The first level inspection has also been performed on Port Said unit 1 after approx 4500 EOH without remarks.

9. Summary
The SGT-700 has been launched with satisfying results and sites are reporting high reliability and availability during the first 28 000 operating hours. The fleet leader has by October 2005 reached 7000 operating hours and is in commercial operation. In close cooperation with our customers, we will continue our extended first level inspection with the fleet leaders. The inspections have shown results in line with our expectations– the core engines are in very good condition. The findings so far are in the installation/auxiliaries of the gas turbine, which means that it is easy to take corrective measures – which have been done – and the consequences for the end users are minor.

The next step (for the engineering team) is to continue with the extended inspections as planned. After 10,000 operating hours turbine blading will be subjected to metallurgic and visual inspection. Data from our Condition Monitoring System is continuously retrieved from sites and evaluated in order to check non-conformances. On-line evaluations are made periodically depending on findings/disturbances in normal operation.

The introduction of the SGT-700 has passed the first critical phase and been given acceptance by our customers. Key indicators show maturity as the next step and the number of delivery slots has been extended accordingly to meet the required number of units in the coming years. Meanwhile, the reference fleet of seven units will be carefully monitored for progress and risk will be evaluated continuously.