FIELD EXPERIENCE FROM 2ND GENERATION OF LOW EMISSION COMBUSTION CHAMBER

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Summary

In 1991 a unique DLE (Dry Low Emission) combustion system was introduced into the SGT-600 25MW gas turbine (then called GT10B). Recently this fleet passed the milestone of 3.5 million accumulated operating hours.

The technology of the combustor is simple: it has no moving parts and only two control valves for pilot gas and main gas. No staging is used for the combustion, but the NOx-emissions are kept at a level of 25 ppm at full and part loads. In order to keep the CO-emissions also at a low level at part loads, an optional combustion by-pass system is available.

In order to ensure a high reliability level for the DLE combustion system, a specific calibration procedure was developed and included in the quality control before delivery. No mapping is required over time since there are no parameters in the control that are drifting over time.

The first positive field experience of combustion of a MBTU-gas (medium calorific heating value) using this technology has been demonstrated in China at an LNG plant. The fuel for this SGT-600 installation varies from natural gas to a process gas consisting of methane diluted with up to 28% nitrogen. The experience accumulated so far shows that a standard SGT-600 DLE unit can start and operate reliably with low emissions on very much diluted natural gas.

The combustion test showed that the standard combustion system could handle up to 35 vol-% N2 in the fuel.

Since this technology is reliable, simple and therefore low in cost, it has now become the standard configuration for a SGT-600 and the conventional combustion system, previously standard, is available as an option for customers whose turbines run primarily on liquid fuel.

Introduction
The development of the DLE-burner started as long ago as the mid-eighties in co-operation with ABB. In 1986, a first generation DLE-burner was introduced (not in the SGT-600/GT10B, however, since the original design was for silo combustors) with a NOx-level of 75 ppmv (dry).

The experience from this development was used when designing the 2nd generation of DLE burner. In 1991 this burner was introduced specifically for the SGT-600 gas turbine and, over the years, 180 SGT-600 units have been equipped with the 2nd generation burner. This corresponds to almost 85% of the total number of units sold. The accumulated operating experience with the 2nd generation DLE burners is more than 2.5 million hours.

The technology used is lean, pre-mixed fuel in a two-slotted cone/burner (see below). With this burner the NOx-level is established at a guarantee level of 25 ppmv (dry). A total of 18 burners are used in the annular combustion chamber of the 25 MW SGT-600 and this arrangement has now, as of two years ago, become the standard burner for the SGT-600, with a conventional burner as an alternative option.

**Technology**

The SGT-600 DLE combustor is a seam-welded film-cooled combustor. The 18 burners are welded on to the combustor back wall and 18 fuel rods are mounted to the burners from the outside. Pilot gas and main gas are supplied through these fuel rods. For dual fuel engines, oil is also supplied through the fuel rods. Water can be added to the oil in the fuel rods as an emulsion.

The SGT-600 DLE combustor is based on the aero-derivative film-cooled concept, which means a simple and robust combustor. The combustor is coated with a normal aero-combustor thermal barrier coating. The life experience is very good and the service concept is well established. The lifetime for the combustor hot parts is 40,000 hours and
there is possibility of recoating and repair during the normal hot part inspection after 20,000 hours.

**Fig. 1, SGT-600 DLE combustor system.**

The pilot gas (stage 1) enters in the tip of the burner and creates a stabilizing flame at part loads. The main gas (stage 2) enters the burner slots and mixes well with the high amount of burner air before combustion, thus creating low flame temperature and low NOx. The liquid fuel enters in the burner tip and burns in a similar way to the pilot gas flame.

**Fig. 2, 2nd generation burner.**
To achieve lower CO emissions at part load, a combustor bypass system is available as an option. The bypass system is integrated into the turbine casing. The system consists of 6 valves controlled by one actuator. Opening of the bypass valves means that the airflow to the burners decreases, the flame temperature increases and the CO emissions decrease. The bypass system keeps the flame temperature and the emission levels constant at 70 to 100% load.

**Fig. 3, SGT-600 DLE bypass system.**

The combustion stability and emissions are kept at low levels over the load range by only two parameters, namely pilot fuel ratio (PFR) and bypass opening.

**Fig. 4, SGT-600 DLE combustor, operational characteristics**
Experience
The SGT-600 DLE combustor has accumulated 2.5 million operating hours of valuable field experience. In the following, the main characteristics of the DLE combustion system are followed up:

- Emissions
- Pulsations

The influence of the hardware and software configuration of the DLE combustion system on the above-mentioned parameters has been analyzed for the different environments and operating conditions. The results of these analyses were used for further system improvement, including software, hardware, calibration and quality control improvements.

Emissions and pulsation
The accumulated SGT-600 field experience (GT10A and GT10B type machines, where the GT10A is the predecessor of the GT10B, the current SGT-600) showed that, in some conditions, mainly in conjunction with incorrect gas valve characteristics, the DLE
combustion system could experience a malfunction – increased emission and/or elevated pulsation level.

It was also found that the original control system:

- should be more carefully adjusted to the ambient conditions (winter, summer) in order to keep the emissions and pulsation at the appropriate levels,
- could not reflect the compressor condition (dirty compressor).

In order to overcome these issues, the existing emission control system was improved and appropriate modifications were made. In the new SGT-600 products, this new emission control system is available as a standard. For the rest of the fleet the new control system is offered as an option for retrospective installation.

The emission control system was designed to meet the following criteria:

- Simple and robust solution,
- Reduced combustor instability (pulsation) at all loads,
- Simple to adjust for each machine (if necessary),
- Independent of specific outer conditions and condition of the compressor.

The emission control system is based on the flame temperature, which reflects the thermal load on the combustor and compensates for ambient temperature, relative humidity and cleanliness of the compressor.

The emission control system controls the bypass opening and the PFR (pilot fuel ratio) in order to keep the flame stability with safe margins at all ambient conditions. The figure below shows the stability limits for the PFR settings.
The available field experience showed that, in order to increase the reliability of the DLE combustion system and finally the combustor itself, a special calibration procedure of the gas control valves should be implemented. This special calibration procedure was developed together with the supplier of the gas valves and implemented in the quality control prior to delivery.

**Future scenario**

**Heating value**

The majority of the SGT-600 DLE engines operate on normal natural gas. However, a number of units in the Netherlands operate successfully on Groeningen gas, which has 80% of the heating value of normal natural gas\(^1\). Recently an order was received from China for combustion of a MBTU-gas (medium calorific heating value) with only 60% of the heating value compared to normal natural gas. The potential problems with very low heating values are pulsation and flame position. Prior to this order, single burner tests were performed to test the lower limit for the heating value. The test was performed with an increasing nitrogen dilution of the natural gas in main and pilot gas separately. The conclusion of the testing was:

- Increased nitrogen dilution in the main gas moves the flame upstream.
- Increased nitrogen dilution in the pilot gas moves the flame downstream.

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\(^1\) Normal natural gas is a defined gas with a LHV of 46.8 MJ/kg
These phenomena could be handled with the current standard design without modifications for the China gas, though modifications to the PFR control have to be introduced. To handle even lower heating value than the China gas, the main and the pilot gas holes have to be increased to adjust for the above phenomena. Design rules for this scaling have been established.

Emissions
Further development has been carried out on the lean mixture principle, with a four-slot cone and an added mixing tube that will reduce the emissions further (down to 15 ppmv NOx, dry) - the 3rd generation DLE is already a reality. This type of burner is already standard in the 29MW SGT-700 (formerly GT10C) and 45MW SGT-800 (formerly GTX100) (some 35 engines sold to date) and one installation already exists for the SGT-600.

Conclusion
The technology used for the 2nd generation of DLE combustion has now accumulated a vast bank of operating hours and is a fully mature product. The improvements made over the years have mainly been on the controls and, as of 1999, very good operation experience has been registered with the PFR control.

Since the technology is simple, a further stretching of the limits in terms of heating value is seen as a low risk.

The first positive field experience of combustion of a MBTU-gas (medium calorific heating value) using this technology has been demonstrated in China at an LNG plant. The fuel for this SGT-600 installation varies from natural gas to a process gas consisting of methane diluted with up to 28% nitrogen. The experience accumulated so far shows that a standard SGT-600 DLE unit can start and operate reliably with low emissions on very much diluted natural gas. The combustion test showed that the standard combustion system could handle up to 35 vol-% N2 in the fuel.

The SGT-600 DLE combustor technology is reliable, simple and therefore low in cost, it has now become the standard configuration for a SGT-600 and the conventional combustion system, previously standard, is available as an option for customers whose turbines run primarily on liquid fuel.