ENVIRONMENTAL UPGRADING OF GTN-16 GAS-PUMPING UNIT COMBUSTION CHAMBER

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ABSTRACT

The results of research into development of engineering approaches to environmental upgrade of the GTN-16 16 MW gas-pumping unit combustor are presented. The built-in "disc" combustor of the GTN-16 is noted for having a small length and very low hydraulic resistances. The multi-burner low-NOx combustor design was developed in a test rig. The "lean" fuel/air premix combustion was adopted as the basis for the design.

The proposed environmental upgrade of the GTN-16 combustor does not bring about any changes in the most costly material-intensive and labour-consuming components of the combustor, viz., casing, frame, liners. No changes were also made in the automatic control system. It is noteworthy that a similar approach is appropriate for the "Turbomotorny Zavod" (Ekaterinburg, Russia) GTN-25 type 25 MW unit.

INTRODUCTION

Many attempts have been made recently by quite a few companies to update gas turbine combustors to achieve a reduction in NOx emissions [1-6]. All the proposed engineering approaches involve a substantial gas turbine unit redesign including replacement of casing components and introducing changes in the automatic control system, etc. This results in a higher cost of redesigned structures. For units that have been in service for many years and which service life has been already notably depleted, use of costly approaches seems to be economically ungrounded.

The objective of the present paper is development of a comparatively low cost approach to update environmentally the GTN-16 gas-pumping unit combustor design. This sought-for approach is expected not to involve a redesign of the unit's casing and automatic control system elements. One more originality of the present paper is as follows: we deal with a built-in annular disc-type combustor with a number of specific features which will be discussed below.

The 16 MW GTN-16 gas-pumping unit has been produced by the "Turbomotorny Zavod" (Ekaterinburg, Russia) since 1983. At present there are 60 units of this type run on the RAO "GAZPROM" gas pipelines.

The problem, though, is that the GTN-16 units do not meet the current Russian emissions standards (NOx=252 mg/Nm^3, CO= 280 mg/Nm^3 at 15% O2). Given the world-wide tendency to make the standards tougher, these units have become obsolete and seemingly having no prospects in future.

Due to this, the RAO "GAZPROM" underwent engineering design changes to improve the environmental compatibility of the GTN-16 unit combustor. At present these activities are in their final phase, this is the test and operational development of the pilot low-NOx combustor.

1. SALIENT FEATURES OF DESIGN AND MAIN CHARACTERISTICS OF GTN-16 COMBUSTOR

The GTN-16 gas-pumping unit combustor applies to the family of "disc" combustion chambers which are not widely used. The burner axes of these combustors are in the plane perpendicular to the axis of the machine. Fig.1 shows the longitudinal (a) and cross (b) sections of the GTN-16 combustors. The summary of its main characteristics is shown in table 1.

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Critical analyses of the G1N-16 combustor design and, also, being guided by the experience gained by the “EST” Ltd specialists in the field of environmental updates of the combustors of other types[7-10], it was admitted to carry out the GTN-16 combustor modification by two stages. At the 1st stage, the combustor’s environmental records were supposed to be improved to the values compliant with the current Russian standards (NOx ≤ 150 mg/Nm³; CO ≤ 300 mg/Nm³ at 15% O₂).

At the 2nd stage, NOx and CO emissions were envisaged to be reduced to values not above 50 mg/Nm³ which is in line with the current world-wide technology level.

2. 1ST STAGE OF OPERATIONS

A technique of local air blow-in into the high-temperature fire zones was applied at the 1st stage of the environmental update of the GTN-16 combustor to reduce the NOx emissions [8,9]. The technique had been already used to advantage at environmental modifications of GT-750-6 (6 MW) and GTG-10 (10 MW) “Nevsky Zavod” gas-pumping unit combustors, GTG-1500 (1.5 MW) “Proletarsky Zavod” turbogenerator, and other machines. Currently, about 450 gas-turbine units, redesigned using this technique, are in service.

The key goal of the technique is to reduce the temperature in the hottest flame zone to about 1500-1600°C. At these temperatures, the combustion reaction rate is reasonably high while the NOx formation reaction rate drops substantially.

A distinctive benefit of the local air blow-in technique is its simplicity and adaptability to manufacture. The environmental update of a combustor using the technique involves typically accommodation of additional air-guide pipings on the dome or on the liner. A challenge here is identification of location, sizes, number and angle of pipings inclination. Semi-empiric formulae are utilized to identify the geometry of the pipings.

Fig.2 shows a GTN-16 combustor dome segment updated using the local air blow-in technique. Here, a standard burner (1) is mounted in the conic shell (2). Eight pipings (3) of d = 32 mm diameter are placed in pairs on four sides of the shell. Aiming to maintain the hydraulic resistance of the combustor constant, the mixer holes were closed by 30%.

The following toxic components concentrations (converted to 15% O₂ concentration) were recorded in the waste gases at the tests of the pilot combustor as part of a gas-pumping unit at the Krasnoturyinskaya compressor station (“Tyumentransgas”) with the unit run at the rated duty:

- NOx (converted to NO,) - 130 mg/Nm³;
- CO - 1400 mg/Nm³.

So, regardless of achieving the target NOx emissions level, the final result is, at large, inadmissible due to the high CO concentration.
To reduce the CO emissions, making the primary zone longer is required, i.e. one should enlarge the burner to mixer distance which is impracticable due to the above features of the GTN-16 combustor design. Hence, a decision to discontinue the 1st stage activities was taken with follow-up focusing on the 2nd stage target solution.

3. 2ND STAGE OF OPERATIONS

The only commercialized fuel firing technique at present which is applicable under the gas-pumping station operation conditions and capable of achieving the NOx and CO emissions level below 50 mg/Nm3 (at 15% O2) is the "dry" NOx emissions suppression with pre-mixed "lean" fuel and air combustion. In our efforts to develop a low-NOx GTN-16 combustor, we made up our minds to follow the same course.

Given the tough requirements to be met by the engineering approach in terms of environmental update of combustors [9], the following concept of the GTN-16 combustor upgrading was adopted:

- the burner diameter is diminished and the number of burners used comes up to 80, these measures allowing reduction of the flame length;
- the number of the fuel-supply tubes is maintained the same and no changes are made in the combustor casing design;
- upgrading of the fuel-distribution system is carried out, i.e. more fuel manifolds are used and no changes are made in an independent fuel supply automatic control system.

The main problems to be solved in the course of the test rig developments of the GTN-16 low-NOX combustor design were thus identified:

- operational development of a single combined burner design;
- operational development of a dome segment burner unit design;
- operational development of a burner unit control algorithm.
3.1 Test rig combustor model

The operational development of the low-NOx combustor design was carried out on the test rig sector model (see Fig.3) which is 1/20th of the full-scale GTN-16 combustor. Aiming to simplify the test model design, it was made axisymmetrical. Along with it, the pattern of change in both the section area of the combustor proper and the area of air supply holes over the combustor length is the same for the model and full-scale cases. Thus, the combustor sector model is two taper shells (1),(2) placed in series; the 1st shell has a perforation and simulates the dome segment while the 2nd one simulates the liner with the mixer holes. A ledge simulating the full-scale combustor ledge formed with the dome hooks is in the conic shells joint.

Fig. 3 Test rig GTN-16 combustor sector model

The test rig model dome is made dismountable and its design can be easily transformed. Fig.3, in particular, shows the test rig sector with the GTN-16 standard dome model.

The tests of models were carried out in the test rig at pressures close to atmospheric ones and at the actual media flows and temperatures. Such methodology is widely used at operational developments of combustor designs using test rigs, it enables to achieve a notable reduction of expenses.

Along with it, using the known relationship

\[ NO_x^f = NO_x^{\text{mod}} \frac{P_f}{P_{\text{mod}}} \]

where \( NO_x^f \), \( NO_x^{\text{mod}} \) are the nitrogen oxides concentrations in the combustion products of the full-scale and model combustors; \( P_f \), \( P_{\text{mod}} \) are the pressures in the full-scale and model combustors;

it is possible to predict the NOx emissions from the full-scale combustor with a reasonable accuracy.

3.2 Operational development of single-burner design

Fig. 4 Combined burner

Fig. 5 shows the GTN-16 combined burner and standard burner emissions records obtained in the test rig at atmospheric pressure. As is obvious from the diagrams, the emissions records of the combined burner are close to those of the standard one operating in the diffusive mode.

With the combined burner operating in the premix mode, the NOx emissions decrease drastically, the burner steady-state operation range, however, suffers a notable narrowing, e.g. a “lean” flameout used to occur at the excess-air coefficient of \( \alpha \sim 4.6 \). What of a practical interest is that with the combined burner operating in the premix mode there is still a certain range of modes (\( \alpha \approx 3.8 \sim 4.5 \)), over which the NOx and CO emissions are reasonably low. Regrettfully, this range of modes is too narrow to ensure a low toxicity of the combustion products with all the modes of the combustor operation. To attain this, complex multi-stage fuel combustion systems should be applied.

3.3 4-burner dome module

Operational development of the 4-burner dome module enabling to put into effect a multi-stage fuel firing was carried out at the follow-up stage of the test rig research works. The 4-burner module test rig model design is shown in Fig.6. The module consists of the four combined burners described in the above section. It is located over the pilot diffusive burner axis. The fuel gas delivery is provided to all the burners via the central tube. The test rig model fuel-supply
tube design enables to control the fuel flow through each burner independently.

Fig. 5 Emissions from combined and standard GTN-16 burner

Fig. 6 Test rig dome model with 4-burner module

Availability of the pilot burner enhances the flame stability. The “lean” flameout critical value is close to α=6 even at a relatively low (around 4%) fuel flow through the pilot burner. With the 30% fuel supply through the pilot burner, the “lean” flameout did not occur until α=15. It is also evident from the diagrams that the NOx emissions tend to rise notably with increasing the fuel flow through the pilot burner.

Operational development of the 4-burner module control algorithm in the test rig was carried out by means of investigating its emissions at a various number of the burners operating in the diffusive and premixing modes. The data obtained allowed identification of an optimum 4-burner unit control algorithm with the load varying from idling to rated duty (Fig. 7). The 4-burner unit operation at idling and low load duties goes on with all 4 burners of the unit operating in the diffusive mode (I stage). Three burners operate in the premixing mode (II stage). In the end, all 4 burners of the unit operate in the premixing mode at loads close to the rated one (III stage).
3.4 Pilot full-scale low-NOX combustor

The pilot full-scale low-NOX combustor was sized and manufactured in compliance with the design and control algorithm of the 4-burner unit developed in the test rig. Fig. 9 shows the combustor. As can be seen from comparison of Fig. 1 and Fig. 9, the proposed environmental update of the GTN-16 combustor does not involve any changes in the most costly material-intensive and labour-intensive components.
The standard unit of control valves consuming combustor components, i.e. casing, frame; liner designs remain the same. At large, the standard combustor upgrading reduces to as follows:

- 20 segments of the standard dome are replaced with the 4-burner module segments;
- a partial closing of the mixer holes in the standard liner is implemented;
- three additional fuel manifolds are mounted outside the casing;
- an independent 4-burner module operation control unit is placed downstream of the standard unit of the fuel control valves.

The schematic diagram of the independent control unit is shown in Fig.10. The schematic enables to implement the 4-stage control algorithm selected using the 4-burner unit rig test results (see Fig.8).

CONCLUSIONS
Preparations for the pilot full-scale low-NOx combustor as part of the GTN-16 unit are underway. The assembly and erection works are being carried out nowadays. Two pressing issues must be solved through a full-scale testing of the pilot combustor. First, it is necessary to verify reliability of the combustor operation at the actual media pressure and to study its characteristics over the overall range of the unit operating conditions. Secondly, it is necessary to carry out tests and adjustment of the independent unit of the 4-burner module operation control. It looks likely that by the time of presentation of the given paper at the TURBO-ASIA'97 some full-scale test results will be already available.

REFERENCES