Technical Condition Assessment of the Gas Turbine Units with Free Power Turbine

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1 Introduction

In accordance with the development strategy of the Russian gas industry, one of the tasks is to reduce the cost of gas transition. Thus, up to 5–8% of the gas pumped through main gas pipelines (MGP) is used as fuel gas for the operation of mechanical drive gas turbine units (GTU) [1]. The fulfillment of this task is impossible without the implementation of a system aimed to ensure the most energy efficient and reliable operation of the gas-compressor units (GCU)—the main equipment of compressor stations (CS). Such a system, in particular, provides monitoring of the GTU technical condition (TC) [2].

Assessment of the gas turbine's technical condition, as well as any equipment, is of particular importance for optimal utilization, timely maintenance, increased MTBF, and overall service life.

Today, the gas transmission system has many diagnostic systems and devices intended to diagnose the condition of the GTU in real time. Most of them are aimed to identify dangerous phenomena and prevent emergency situations, as well as eliminate the risk for service personnel's life and health. These diagnostic methods include measuring the temperatures of lubricating and cooling liquids, elements of the hot gas path, anti-surge protection of compressors, and vibration measuring. In this case, any deviation of one of the parameters from the permissible deviation limits may mean the imminent emergency.

Nevertheless, there are not so many systems and algorithms aimed specifically at online monitoring of the efficiency and efficiency degradation rate of this equipment during the life cycle. In some cases, it is not possible to determine, for example, how much the maintenance has affected efficiency increasing. Real-time TC monitoring

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can be used for remote monitoring of the GTU technical condition and early planning of repair operations.

In the modern gas transmission industry, the most widespread ones are two-shaft and multi-shaft GTU with a dedicated power turbine, unlike power GTUs, which are often used as single-shaft plants.

2 Materials and Methods

When assessing the GTU technical condition, it makes sense to consider and analyze both integral and local parameters of the TC (Table 1). Tracking the degradation of these parameters will make it possible to assess and predict the GTU technical condition with the prediction of probable malfunctions of separate units and a GTU as a whole [3, 4].

Integral parameters are those that characterize the operation of the GTU as a whole. For example, effective and available power, effective efficiency, technical condition coefficients for power, efficiency and fuel gas consumption, etc.

Table 1 Classification of integral and local parameters of the GTU technical condition

Parameter name	Classification
Technical condition coefficient for GTU power	Integral
Technical condition coefficient for GTU efficiency	Integral
Technical condition coefficient for GTU fuel gas consumption	Integral
Actual reduced power of GTU at nominal mode	Integral
Actual effective efficiency of GTU at nominal mode	Integral
Actual reduced fuel gas consumption of GTU at nominal mode	Integral
Reduced temperature of combustion products in the turbine (at any point of measurement)	Local
Temperature imbalance of combustion products after the last GTU turbine	Local
Air pressure behind the GTU axial compressor	Local
Polytropic efficiency of GTU axial compressor	Local
The efficiency of separate GTU units (calculated according to the measured parameters, the possibility of use depends on the type of gas turbine and the number of measured parameters; the efficiency values can be calculated approximately using mathematical models of GTU elements and used as auxiliary criteria of the technical condition)	Local
Reduced rotor speeds	Local
Vibration displacement and vibration velocity	Local
Local parameters (parameters measured for monitoring and control of separate GTU systems, for example, anti-icing, lubrication system, etc. The scope of measurements and recommendations for their control are provided by the GTU manufacturer)	Local

Local parameters are the TC parameters of separate GTU units (axial compressor, combustion chamber, gas turbine, bearings, etc.), as well as elements of these units (for example, a blade row). To assess the technical condition of separate units, the power generated or consumed by them, polytropic and adiabatic efficiency, qualitative and quantitative changes in the key parameters of these units operation under various conditions, and other factors are also used. In general, local parameters affect the integral ones.

Today, the technical condition coefficients (TCC) are most often used as the criteria for evaluating TC in operation. Based on the TCC data of the entire GCU fleet, a rational choice of load distribution of compressor yards, CS, and MGP in general is made. In addition, this criterion is used to control the quality of the unit repair. The TCC of a GTU can be determined by the power of the unit, its efficiency, and fuel gas consumption. For example, to estimate the TCC by power, it is required to establish the reduced available power, which a GTU develops in the actual technical condition, and refer it to the nominal (rated) power. The reduced available power is understood as the effective power, which is developed by a GTU, which has the actual condition, under standard station conditions when the nominal value of any parameter is reached.

The most widely used method for determining the power of a GTU is by the power consumed by a centrifugal gas compressor (CGC). For this, the head pressure developed by the CGC is determined by the "enthalpy" method or by the polytropic Schultz method [5] using measurements of the temperature and pressure of the compressed gas at the inlet and outlet of the CGC, as well as by the known gas composition. The critical influence in this case is the accuracy of temperature measurement. Another problem of this method is the accuracy of determining the process gas flow rate. The absence of individual measuring units for the GCU leads to the necessity to determine the CGC performance by other methods: by the pressure drop across various kinds of constriction device (a confuser or a suction chamber), or indirectly by the CGC characteristics. The first approach is associated with determining the exact confuser coefficient: such devices require individual calibration due to technological deviations in geometry, pressure taps installation locations, and differences in the piping of gas compressors, and such calibration in the absence of a more accurate flow meter in the unit is an impossible task. To improve the measurement accuracy, various flow meters are used, for example, an ultrasonic flow meter, but this requires specialized tests using expensive equipment. The application of the CGC gas-dynamic characteristics to determine the gas flow rate in most cases shows significant divergences in the data obtained from the actual values. This is due to the fact that when obtaining factory characteristics, the air is used as a working fluid, and then the obtained characteristics are recalculated from air to gas. In addition, inaccuracies can be caused by restrictions on the number of tests with a large range of characteristics, the lack of the CGC piping influence consideration.

In the last quarter of the twentieth century, Gazprom VNIIGAZ carried out the work to summarize the results of heat engineering tests of gas pumping units operated at CS. The authors [6] have made an explication of the generalized characteristics, based on new aggregates. However, using this method, the particular gas turbine power determination accuracy may be unsatisfactory.

Other methods for calculating the power of a GTU do not use data on CGC operation. One of these methods assesses the available power and TCC from the shift in the GTU characteristics [7]. This method requires the presence of factory characteristics or characteristics obtained during acceptance tests carried out before the GTU is put into operation to check their compliance with the requirements of state standards and technical documentation. But, as a rule, a GCU manufacturer does not provide such characteristics in sufficient volume.

Moreover, GTU power can be determined from the heat balance compiled for the control volume [8]. This method is difficult to implement in operational conditions, it requires additional measurements, and its application for each GTU is almost impossible.

The methods described above are based on the thermo gas-dynamic parameters of the GCU operation. A different approach is implemented when determining power using a torque meter (TM). This approach has not found wide application, since it requires the use of expensive equipment, which, moreover, must be periodically sent to the factory for calibration.

Another trend is based on using parameters of a power turbine to determine the efficient power of a GTU. In the current paper, the authors present some results of this method application.

3 Results and Discussion

The perspective method for determining the effective power of a GTU is the approach described by the authors in articles [9, 10]. The feature of this approach is the use of standard measurements of the GTU operation parameters. It was a common knowledge that the effective power of a GTU is the power developed by a power turbine (PT). In the described work, the PT power is determined from the heat drop and the gas flow rate. In this case, gas-dynamic functions are used to calculate the gas flow rate.

This technique has been tested on several types of gas turbine units. Nowadays, more than 500 units of the studied types are in operation. The implementation procedure is currently in process. For this, verification of the design models was carried out on the basis of field tests of several units. The work was carried out on several units, representing different types and different powers: 10, 12, 16, 25, and 30 MW, as well as different purposes of engines: stationary, aero-, and marine derivative. For example, Figs. 1 and 2 show the test results of 30 and 10 MW GTU, respectively.

Figure 1 shows the experimental dependences for two GTU-30. Trend lines were plotted from the measured points and then parameters for the nominal exhaust temperature were determined. The coincidence of the power values determined by the proposed method [9, 10] and by VNIIGAZ [5] lies within 2% for both GTUs. Power

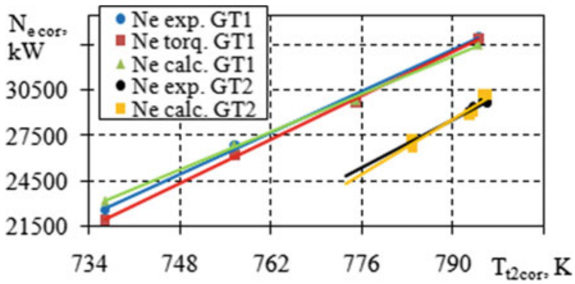

Fig. 1 Test data for GTU-30

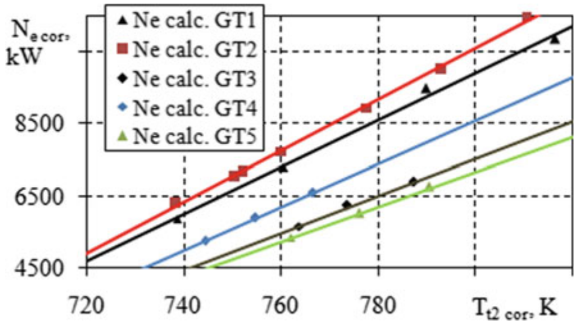

Fig. 2 Test data for GTU-10

was also determined for the GT1 using a torque meter (Ne torq.) [11]. R.M.S. deviation Ne torq. of powers determined by thermo gas-dynamic parameters does not exceed 2.5%. The deviation of the gas turbine power by several methods at once can be used as a reliability criterion of the data obtained in the gas turbine diagnostic systems, as well as the calibration of one approach relative to another.

Figure 2 presents statistical information for five units of GTU-10. All points were calculated according to the presented method [9, 10] based only on standard measurements with calibrated measuring instruments. The obtained values of the GTU power were also checked using the methodology [5] based on the test results. The lines shown on the chart are trends for their group of points. As can be seen, these engines have different technical conditions. This is mainly due to the fact that each of them has a different operating time after repair. Figure 2 shows that the shift of the trend line can be judged on the degradation of the technical condition of a particular unit. At the same time, it is not necessary to determine the exact value of the GTU power, and the main thing is to track its quantitative change (for example, in %). In addition, it is not necessary to start tracking from the "ideal" GTU condition. This feature can be used in diagnostic systems for assessing and predicting the GTU technical condition degradation [12–15].

The described technique for assessing technical condition can be used to quantify the effectiveness of repair and restoration measures based on normally measured parameters. It means that a GTU can be tested before and after maintenance (compressor washing, restoration of radial clearances, etc.), and the results can be used to note the effect of the event.

4 Conclusion

The paper analyzes various methods for assessing the technical condition of gas turbine units with a free power turbine and considers the main indicators of the GTU technical condition. The method for assessing the coefficient of GTU technical condition by power and efficiency has been implemented, which has shown good convergence with experimental data obtained using measurements of the power consumed by a centrifugal compressor. For each type of GTU with a separate power turbine, it is theoretically possible to implement the principle of monitoring the technical condition in real time using normally measured parameters. The considered method can be used to quantitatively assess the effectiveness of repair measures, which is extremely important for a large gas transmission system operating more than a thousand gas pumping units. Tracking the degradation of technical condition indicators will allow us to assess and predict the technical condition of the GTU with the prediction of probable malfunctions of separate units and GTU as a whole.

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