Features of noise radiation from gas turbines

V B Tupov and A A Taratorin

Thermal Power Plants Department, National Research University “Moscow Power Engineering Institute”, Krasnokazarmennaya str., 14, Moscow, 111250, Russia

TupovVB@mail.ru

Abstract. Gas turbine unit (GTU) is the most intensive source of constant noise during normal operation. The noise of the gas turbine unit is emitted from the compressor intake, from the installation shell and from the chimney mouth of the gas turbine unit. Mathematical models for GTU of various capacities are compiled. It is shown that the determining role plays the noise from combustion. That noise is radiated from the chimney outside. Considered various factors affecting noise emission. Obtained empirical formulas for calculating the noise level at various distances depending on the power of the gas turbine. For the first time indicated the importance of taking into account regional climate factors to determine the required noise reduction from GTU. This is especially important to consider when determining the required reduction at high frequencies. The set of factors considered in this paper allows us to determine the required reduction from the gas turbine. Indicated possible measures to reduce noise from gas turbine unit and bring it to sanitary standards.

1. Introduction

The use of combined-cycle gas-fired plants (CCGTs) is currently recognized as the most promising technology for generating heat and electricity at thermal power plants. Most of the generating capacity in the Russian heat power industry is replaced by CCGTs. That units have significantly higher efficiency values compared to steam turbine installations (STU) and are characterized by high environmental indicators. The main element of the CCGT is the gas turbine unit (GTU). GTU is also used to cover the maximum load in electrical systems and is installed at gas pumping stations. At the same time, GTU are sources of intense constant noise at thermal power plants. Noise from GTU in normal operation is emitted from the air intake of the GTU compressor, from the installation shell, as well as from the chimney [1].

The noise impact from the unit shell is determined by the sound-insulating properties of the room where GTU is installed, and is usually small. In addition, GTU is usually supplied in casings. The use of cases allows to meet the requirements of sanitary standards for industrial spaces.

Noise from air intake has an aerodynamic nature. It is emitted into the atmosphere through the air intake path. The noise emitted through the GTU suction system is caused by variable aerodynamic forces. They appear from interaction of the turbulated air from the rotor and stator of the compressor, as well as the phenomena of instability of the turbulent flow. The total sound power of the GTU suction noise depends on many factors: the mass air flow through the compressor, the adiabatic pressure, the outer diameter of the impeller of the first stage of the compressor, the adiabatic efficiency of the compressor. The sound level during operation of a 100 MW GTU compressor radiated through an air intake without silencers is 110 dBA at a distance of 120 m from it [1]. Therefore, all deliveries of GTU
are equipped with noise suppressors in integrated air-cleaning device. Such measure allows to reach the requirements of sanitary standards.

The noise emitted by the exhaust tract of gas turbines caused by the combustion process, a high velocity through a flowing part of the turbine and the turbulence of the gas flow. The noise level emitted from the GTU chimney is less than from the air intake system. For example, the sound level from a 100 MW GTU chimney without a sound attenuation system is 84 dBA at a distance of 120 m from it. As you can see, the noise emitted from the exhaust of GTU through the chimney is determined by the trace of the gas path, the presence or absence of a recovery boiler or other heat exchange equipment, as well as the length of the tract and the material of the chimney. Under certain circumstances, the attenuation of noise in the gas path may be sufficient to meet sanitary standards. Otherwise, silencers must be installed. As a rule, the noise from GTU exhaust is the determining level of acoustic impact of the entire installation on the environment. In addition, as will be shown in this article, GTU noise depends on climate factors and can vary widely throughout the year.

2. Study of GTU noise on acoustic models

For the study, GTU were selected, the acoustic characteristics of which are shown in table 1.

Table 1. Sound power levels of the exhaust gas turbine, dB.

| № | GTU brand and manufacturer | GTU Power, MW | Octave-band frequencies, Hz |
|---|---------------------------|--------------|----------------------------|
| 1 | GTN-16M-1 (UTZ)          | 16.8         | 63 125 250 500 1000 2000 4000 8000 |
| 2 | AL-31STE (UMPO)          | 18           | 130 135 137 138 135 134 129 |
| 3 | SGT-700 (Siemens)        | 29.1         | 137 139 142 143 140 135 128 |
| 4 | SGT-800 (Siemens)        | 47           | 145 148 149 137 136 140 144 |
| 5 | SGT-1000F(Siemens)       | 68           | 140 138 137 139 139 150 134 |
| 6 | GT11N2 (Alstom)          | 114          | 136 135 133 138 142 145 130 |
| 7 | GTE-160 (Power machines) | 157          | 144 139 138 140 144 149 146 140 |
| 8 | SGT5-4000F(Siemens)      | 287          | 145 140 135 140 143 152 143 135 |

Based on the sound power levels of GTU exhausts presented in table 1. Sound power levels was calculated on the out of chimney. The directivity index \( D_c \) for the conditions of the model under consideration takes the following values [1]:

\[
\text{directivity index } D_c \text{, dB} = -2.7, -2.7, -3.2, -3.7, -3.9, -7.9, -11.7, -11.7, -12.6
\]

The directional index is determined for the conditions of the model under consideration, the general view of which is shown in figure 1. The height of the chimney is 60 m and the average distance from the chimney to the calculated points is 380 m.

Calculation models (figure 1) were compiled for all GTU listed in table 1. The number of similar installations varied from 1 to 3. In total were calculated 24 GTU models.

The location of the calculation points relative to the GTU is shown in figure 2. Calculation points in accordance with the requirements of the document [2] are selected at a distance of 300 m from the border of the TPP territory. One of the purposes of the calculation was to determine the irregularity of noise emission in different directions. For this purpose, were selected 36 calculation points in each model. Points are located along a circle with a step of 10°.

As a result of calculations at each point were obtained the values of sound pressure levels (SPL) for the octave-band frequencies of 31.5-8000 Hz and sound levels. In total obtained an array of 8640 values. Analysis of the results shows that the highest values SPL are reached at points to the south of the GTU. This is due to the fact that the chimney is displaced by 30 m to the south relative to the centre of the GTU. Also, the presence of an air intake is a screening obstacle for points located on the opposite side relative to the chimney.
Figure 1. Model for acoustic calculations: a – top view (dotted line shows the location of the GTU for the option with one unit), b – 3D model: 1 – border of the plant territory; 2 – GTU building; 3 – chimneys; 4 – noise source (out of the chimney).

Figure 2. Location of calculation points relative to the GTU.
Typical map of noise propagation is shown in figure 3. Figure 4 shows on the example of the SGT5-4000F (Siemens) how the sound levels change at receiver points depending on the direction angle. It can be seen that with an increase of thermal power plants power SPL’s grow. It is due to an increase of the number of GTU. For the larger power of the TPP the irregularity of the sound levels for different points decreases. In this example for one GTU, the difference between the maximum and minimum values of sound levels was 3.8 dBA, for two GTU – 3.4 dBA, for three GTU – 3.3 dBA.

Figure 3. Noise propagation map.

Figure 4. Sound levels, dBA, in reciever points for different number of GTU.
The calculated point located in the direction of 180° was selected for further analysis because it has the highest sound levels. For this point plot graphs showing the change in the sound levels depending on the number of operating units of the same type and their capacity. The dots on each line of the graph show the sound levels for one, two, and three installations. The numbering of the lines corresponds to the number of gas turbines in table 1. A total was considered 8 types of units with a capacity from 16.8 to 287 MW. All gas turbines operate at nominal mode. The graphs are shown in figure 5.

\[ L_p = 4.187 \cdot \ln(N_e) + A \]  
(1)

where \( N_e \) is the electrical power of the GTU, MW, and the coefficient \( A \) for different GTU:

| GTU brand and manufacturer | \( A \)  |
|---------------------------|--------|
| GTN-16M-1 (UTZ)           | 56.00  |
| AL-31STE (UMPO)           | 57.00  |
| SGT-700 (Siemens)         | 58.59  |
| SGT-800 (Siemens)         | 54.99  |
| SGT-1000F(Siemens)        | 53.79  |
| GT11N2 (Alstom)           | 49.47  |
| GTE-160 (Power machines)  | 54.13  |
| SGT5-4000F(Siemens)       | 53.44  |
For estimation calculations, when the model of GTU is unknown, can be used the following dependence which has an accuracy value of approximation $R^2=0.66$:

$$L_p = 2.628 \cdot \ln(N_e) + 61.84$$

(2)

The error in formula (2) is large. Therefore, the formula (1) is recommended for calculations.

Given that the distance from the chimney out in the model is 350 m, the formula (1) can be converted into a formula for calculating sound level at points located at different distances $d$, m, from the chimney out of the GTU:

$$L_p = 9.64 \cdot \lg(N_e) - 20 \cdot \lg(d) + A + 50.88$$

(3)

When substituting $d=350$ m, formula (3) is converted to formula (1).

3. **The influence of climatic factors on the noise propagation from gas turbine**

When performing acoustic calculations in accordance with ISO 9613.2 regional climate factors only affect the attenuation component of the $A_{atm}$, which is defined as:

$$A_{atm} = a \cdot d$$

(4)

where $a$ is the coefficient of sound attenuation due to sound absorption by the atmosphere in the octave-band frequency, depending on temperature, humidity and barometric pressure, dB/m; $d$ is the distance from the noise source to the receiver point, m. The thesis [3] shows that the influence of changes in barometric pressure can be ignored.

Articles [4,5] present data on the minimum and maximum values of $a$ for Russian cities (see table 2).

| City         | Derbent | Elton | Taganrog | Sochi | Teriberka | Kaliningrad | Sochi | Sochi | Elton | Sochi | Omyakon | Zhigansk | Chita | Kosh-Agach |
|--------------|---------|-------|----------|-------|-----------|-------------|-------|-------|-------|-------|----------|----------|-------|-------------|
| $a_{min}$    | 0.014   | 0.02  | 0.05     | 0.17  | 0.57      | 1.19        | 2.9   | 18.7  | 48.6  | 27.4  | 64.5     | 162.1    |       |             |
| $a_{max}$    | 0.15    | 0.34  | 0.73     | 1.75  | 4.50      | 11.19       | 27.4  | 64.5  | 162.1 |       |          |          |       |             |

The maximum change in the attenuation coefficient of sound in the atmosphere for each octave-band frequency can be determined by the formula:

$$\Delta a = a_{max} - a_{min}$$

(5)

The noise emitted from the GTU chimneys out depends on the type of turbine and has high values at octave-band frequencies from 63 to 4000 Hz. Climate factors have the greatest influence at high frequencies and the least at low frequencies. From the data for 210 cities, the results of calculating the minimum and maximum values of coefficients for octave-band frequencies from 31.5 to 8000 Hz during the year are presented in table 2. It can be seen that the coefficients of sound absorption $a$ for different regions vary greatly depending on the time of year. Therefore, in order to accurately determine the required reduction from chimneys out, taking into account the correct sound absorption coefficient by the atmosphere is an important practical task for the development of sound attenuation measures. The calculation results for the variant with a single SGT5 4000F GTU are given below.

Figure 6 shows the range of changes in sound pressure levels for octave-band frequencies from 31.5 to 8000 Hz. It calculated taking into account the highest and lowest values of the coefficients $a$ over the course of a year for different regions for a point at a distance of 350 m from the mouth of the chimney.
Figure 6 shows that sound pressure levels can vary greatly over the course of a year depending on the region when the sound attenuation coefficients in the atmosphere change. These changes for octave-band frequencies are:

| $f$, Hz | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---------|------|-----|-----|-----|-----|------|------|------|------|
| $L_p$, dB | 0.0  | 0.1 | 0.2 | 0.6 | 1.4 | 3.5  | 8.6  | 16.0 | 39.7 |

It can be seen that as the octave-band frequencies increase, the difference between the lowest and highest values of the ranges increases. The difference in sound pressure levels for different regions varies from 1.4 dB for the octave-band frequency of 500 Hz to 39.7 dB for the octave-band frequency of 8000 Hz.

The maximum value of the sound level at the receiver point (at the minimum values of $\alpha$) was 78.5 dBA, and the minimum value (at the maximum values of $\alpha$) was 72.2 dBA. The change in the sound level at the receiver point, located at a distance of 350 m from the chimney out, reaches 6.2 dBA.

Therefore, in order to accurately determine the required noise reduction from the GTU exhaust, which is emitted from chimney out, and to develop the necessary noise reduction measures, it is necessary to take into account regional radiation factors for this region.

Recommendations [1,6-10] are used when taking measures to reduce the noise level of GTU, including their exhaust paths.

4. Conclusion

1. Considered the features of the noise emissions from gas turbines. It is shown that a determining role plays GTU combustion noise, which is emitted from the chimney out.

2. Considered the factors influencing the noise emission. From the calculated data simple estimation empirical formulas are obtained. That formulas allow calculating sound levels at a distance from the GTU depending on their power.

3. For the first time indicated the importance of taking into account regional climate factors to determine the required noise reduction from GTU. The difference in sound pressure levels for different regions varies from 1.4 dB for an octave-band frequency of 500 Hz to 39.7 dB for an octave-band frequency of 8000 Hz, and the difference in sound levels up to 6.2 dBA at a distance of 350 m.
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