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ABNORMAL RESONANCE NOISE OF EXHAUST GAS PASSAGE IN URBAN COMBINED POWER PLANT

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Abstract

A diffuser of an industrial gas turbine is annular with structural members, called struts, in the exhaust gas flow path. The high noise coinciding with the pressure pulsation tone produced in the combustion cans has been measured near the strut of the gas turbine flue gas passage since the commercial operation of urban combined power plant site in Korea. The pulsation frequency by combustion stimulated the radial standing acoustic resonance of the strut. The abnormal exhaust noise transferred through stacks caused inhabitant to complaint. The acoustic resonance phenomenon in the exhaust passageway of gas turbine was the main noise source of public complaint. Threshold for 585 Hz pulsation from the combustion cans is 3 - 18 kpa, rms. When the load is 80-95% of full, pulsation levels are magnified >100 pa, rms at downstream of diffuser and has 585 Hz component; then, the sound pressure level shows > 101dBA at the top point of the stack. It shows that the noise complaints around the power plant are caused by the resonance phenomena in GT flue gas passage. Baffle silencer is applied to isolate the abnormal noise frequency band into the stack; therefore, the measures obtained insertion loss of 20dBA.

1. INTRODUCTION

Urban combined power plants have many noise sources such as pumps, compressor, air inlet, safety valve, transformer, and smokestack. Specially, a civil appeal is a matter of frequent occurrence from a range of habitation sites close to the boundary line of downtown power plants. As civil appeals were raised due to consecutive abnormal noises in the hillside residential areas or the upper stories of apartments around power plants, the status of noises was investigated. Then an abnormal condition occurred that noise level of harmonic wave at 585Hz was intermittently amplified by 10dBA or more. As a result of investigating surrounding noise sources and plant noise sources, harmonic wave at 585Hz was amplified at the exhaust duct of a gas turbine under certain operating load of a power plant. The abnormal noise of an exhaust duct in domestic power plants is mainly caused by the periodic vortex which occurs when high-temperature flue gas discharged from a boiler vertically flows into tube bundles and the resonance of sound field frequencies at an exhaust duct.

This study describes a situation that abnormally amplified noise at 585Hz generated at the exhaust duct of a gas turbine was transmitted through the smokestack of a power plant, as a case of a civil appeal raised from the surrounding area of a downtown co-generation plant which has recently started commercial operation.

2. SURVEY ON THE POSITIONS OF THE SOURCE OF ABNORMAL NOISE

2.1 Characteristics of abnormal noise generated in the surrounding area of a plant

The surrounding area of a plant is located in a higher area than the plant, so it shows high directivity toward the plant, factories, and roadsides in low-lying areas. Noise was measured with B&K microphone at two points having directivity toward the plant smokestack.

In the surrounding area, 585Hz noise was within 38dBA but it was >48dBA (refer to Figure 1) under abnormal amplification, which indicates that noise was amplified by >10dBA at least in the surrounding area within 1km.

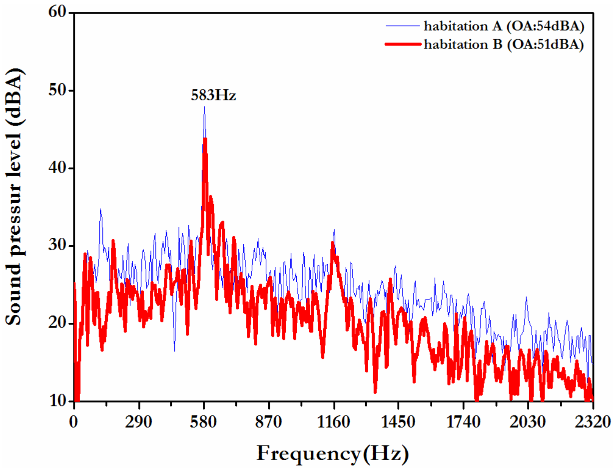


Figure 1. Abnormal noise spectrum in the surrounding area of the power plant

2.2 Clarification of noise source

2.2.1 Characteristic of abnormally amplified noise emitted from the exhaust duct

As a result of investigating the primary transformer, the compressor, the air inlet, the seawater circulating pump and exhaust duct in the plant on the basis of the spectrums of abnormally amplified noises analysed in the surrounding area, 585Hz noise at the exhaust duct was amplified at >80% operation load. Figure 2 shows the exhaust duct of a gas turbine where abnormal sound was found. The abnormal noise that the total noise level was >85dBA was emitted at 585Hz noise that was 80dBA in the noise spectrum.

2.2.2 Characteristic of noise discharged from the smokestack

Figure 3 shows noise spectrum at the outlet of the smokestack in the power plant. Figure 3 shows that the same amplified noise at 585Hz is discharged through the outlet of the smokestack. That is, it is estimated that the intermittently amplified noise at 585Hz which was found in the habitation site would occur at the exhaust path of a gas turbine, pass through the Heat Recovery Steam Generator (HRSG), and be discharged through the smokestack.

Compared to no abnormal amplification, noise at the outlet of the smokestack was increased by 20dBA or more when abnormally amplified noise was transmitted at >80% operating load, and the total noise level was increased from 74dBA to 101.5dBA.

Figure 2. Noise measurement at the exhaust duct of a gas turbine

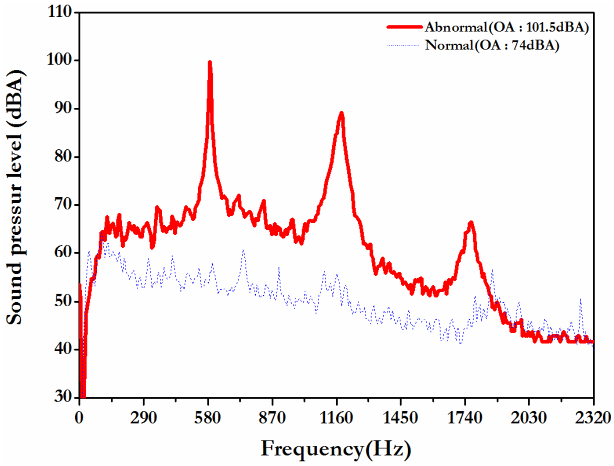


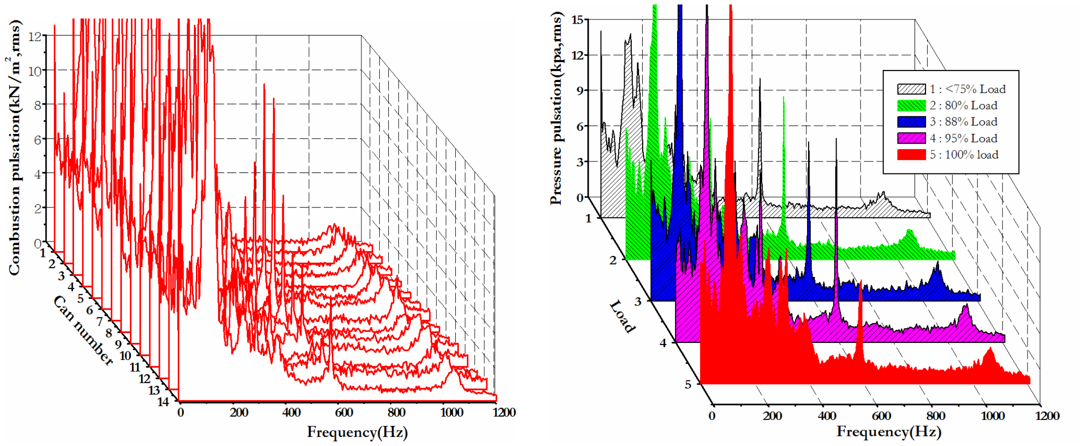
Figure 3. Abnormally amplified spectrum of 585Hz harmonic noises generated from the outlet of the smokestack

3. ANALYSIS ON THE PATHS OF ABNORMALLY AMPLIFIED NOISE

3.1 Amplified pressure pulsation at an exhaust passageway

3.1.1 Characteristics of pulsating pressure from the combustion cans

A gas turbine is designed to rotate by exhaust at high temperature and high pressure incoming from the combustion part. The pulsation of burning vibration generated from the combustion cans may influence the strut, the diffuser and the exhaust duct through the gas turbine, where a possibility may be examined that it may lead to excitation of 585Hz's standing wave of the strut, the diffuser or the exhaust duct. The combustion part of gas turbine is composed of 14 cans, and the dynamic pressure measurement port is installed per can. Figure 4(a) shows the explosive pulsating pressure spectrums of 14 combustion cans as tested at 80% load. The pressure pulsation of 585Hz was found in all the 14 combustion cans which might occur when abnormal noise is amplified at an exhaust duct, and the characteristic of the pressure pulsation nearly equivalent to 585Hz was analysed even under operating load without abnormal amplification at the duct as shown in Figure 4(b); therefore it can be deemed that the abnormally amplified noise at 585Hz shown at the exhaust path of a gas turbine was caused by the pulsating pressure at 585Hz generated from the combustion cans.



(a) Spectrums in cans at 80% load (b) Spectrums of a combustion can by load

Figure 4. Dynamic pressures at the combustion cans of gas turbine

3.1.2 Test of abnormally amplified pulsating pressure at the exhaust duct

Figure 5 shows exhaust pulsating pressure spectrums of the duct as tested under amplification at the exhaust passageway of a gas turbine.

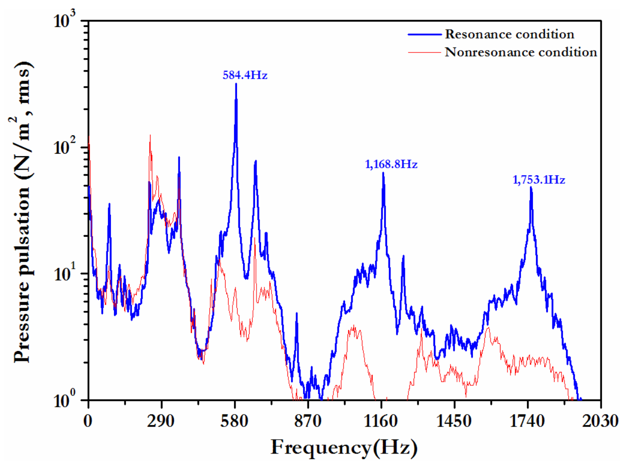


Figure 5. Dynamic pressure spectrum measured at the the exhaust duct of a gas turbine

For exhaust gas pulsating pressure under abnormal amplification, the 585Hz frequency shown in the combustion cans was displayed at the passageway after the gas turbine, and the HRSG displayed passage of the 585Hz frequency. In conclusion, it is estimated that amplification pressure at 585Hz is caused by the situation that sound impedance at the exhaust passageway for 585Hz frequency is lower than other frequencies to be readily passed.

3.3 Abnormal noise at the strut and diffuser of gas turbine

Figure 6 shows comparison of noise spectrums under abnormal amplification as tested at each section of the strut, the diffuser and the exhaust duct. The amplified noise at 585Hz measured at the exhaust passageway was shown to be highest at the strut section as 102.3dBA. It was measured as 85dBA at the diffuser section and 76.5dBA at the exhaust duct, thus the resonance source of standing wave in the exhaust path was estimated as the strut section neighbouring on the last blade stage of a gas turbine.

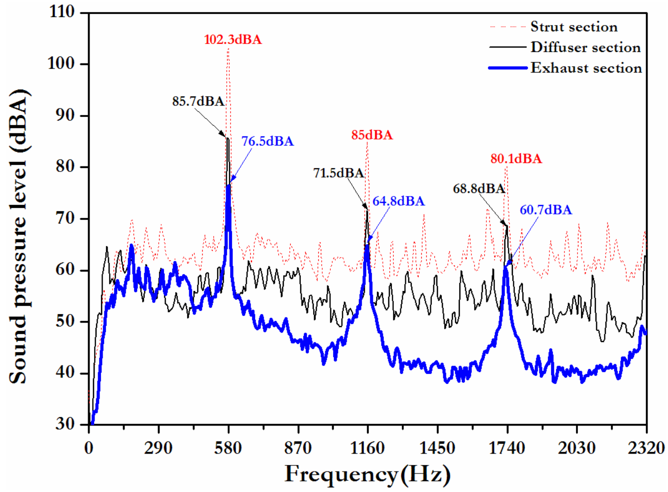


Figure 6. Noise spectrum at each section of the exhaust passageway upon abnormal noise

4. MECHANISM OF ABNORMALLY AMPLIFIE NOISE

4.1 Analysis of shape of the exhaust gas passage

Exhaust is discharged into the discharge duct through the strut and the diffuser at the last stage of a gas turbine blade. The strut and the diffuser has the internal wall of cylindrical type whose diameter is nearly same as shown in Figure 7, and its outer wall is sloping. Usually, it is known that standing wave is little formed at the sloping wall.

(a) strut section (b) diffuser section

Figure 7. Main parts of the exhaust passageway of a gas turbine

Table 1 shows the result of calculating thermodynamic physical values of exhaust passing through the exhaust path after the last stage of a gas turbine. The strut at the exhaust path is neighbouring on the last blade stage of a gas turbine, and the diffuser is positioned between the strut and the discharge duct. Each section of the exhaust passageway is 700~1080mm in the inside of the diffuser, 580~650mm in the strut of the diffuser, and 460~500mm in the strut of the gas turbine.

Table 1. Physical value of medium at the exhaust passageway

Medium	R (J/kmol K)	M (kg/kmol)	Specific heat ratio	Temperature (K)	Sound Velocity (m/s)
Flue gas	8,314	28.3	1.31	875 ~ 890	580 ~ 585

4.2 Analysis of standing wave at the exhaust passage

As a result of examining standing wave at each section of the exhaust path, standing wave mode at about 585Hz in the radius direction of the strut from the stage of the last blade of a gas turbine was calculated, and standing wave of secondary or tertiary mode in the radius or circumference direction from the diffuser was calculated. Figure 8 and Figure 9 show a result of finite element analysis with ANSYS code to verify estimated standing wave and analyse the development form.

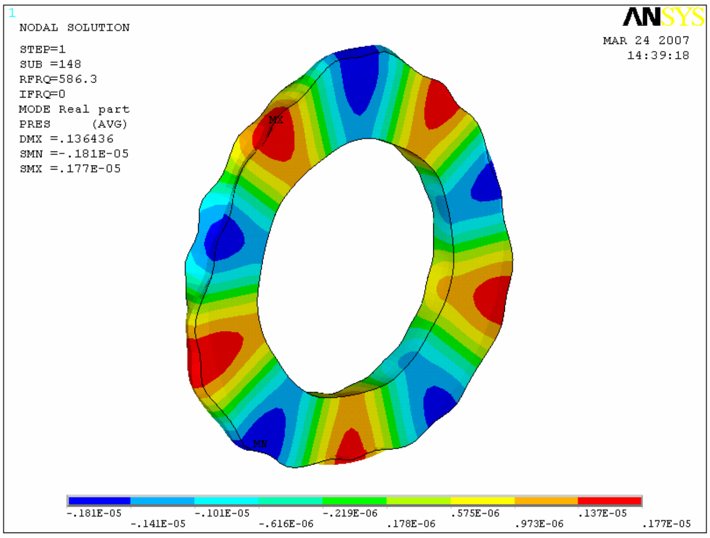


Figure 8. Acoustic mode of 586.3Hz at the strut section in the exhaust path

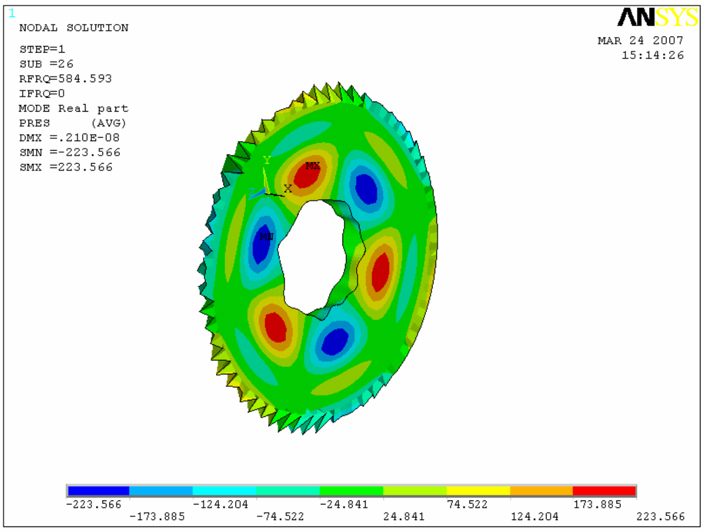


Figure 9. Acoustic mode of 584.6Hz at the diffuser section in the exhaust path

Figure 8 shows resonance mode in the radius direction at 586.3Hz as analysed at the strut section from the gas turbine, which is represented into 577Hz and a pair. When the result of Figure 5 and Figure 6 is compared to that of Figure 8, it is derived that at the strut section of double cylinder structure, as the strength of vibration source is fully increased, resonance of standing wave in the radius direction occurs if the inner cylinder wall has horizontal structure even if the outer cylinder wall is sloping. Figure 9 shows resonance mode at 584.6Hz as analysed in the circumference direction at the diffuser section from the strut, which is represented into 574.6Hz and a pair. 585Hz at the diffuser from the strut showed 3rd mode standing wave form in the circumference close to the inner cylinder wall as shown in Figure 7(b); therefore, the position that pulsating pressure at 585Hz arising out of the combustion can pulsating wave at 585Hz at the exhaust path is, primarily, the strut at the gas turbine outlet, and pulsating sound pressure at 585Hz amplified at the strut section is maintained and transmitted in the form of amplifying standing wave of the 3rd mode at 585Hz in the circumference of the diffuser section from the strut, and then it is discharged through the smokestack.

4.3 Countermeasures against inhabitant complaint around power plant site

As countermeasures against abnormal noise, operation of avoiding an amplified operating load zone, change of the characteristics of sound field at the amplification point, and interception of a path at the smokestack may be considered. In this study, however, a countermeasure of installing a noise suppressor in the smokestack from which noise is finally emitted was applied as shown in Figure 10. In this method, as the characteristics of sound impedance of the whole exhaust duct could not be changed, the noise suppressor was designed in cylindrical type for each stage and section interval so that 580Hz wave not be passed, and foamed aluminium of sound-absorbing material was treated on the surface of the noise suppressor so that high frequency components be reduced and then it was attached onto the top of the smokestack in the plant. Consequently, noise from the top of the smokestack was reduced by 20dBA or more as shown in Table 1; the optimal sound-absorbing material of foamed aluminium was obtained.

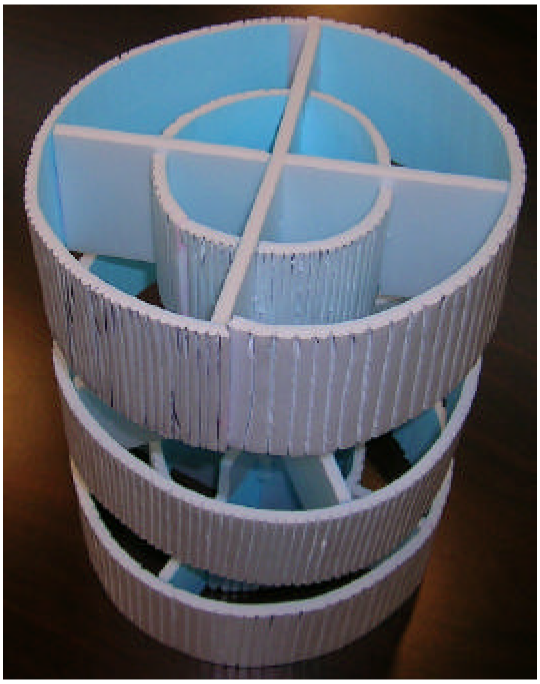


Figure 10. View of the noise suppressor installed in the smokestack

5. CONCLUSION

The mechanism of abnormal noise intermittently occurring in the surrounding area of urban combined power plants and the countermeasures are summarized as below:

(1) Abnormal noise was clarified as a situation that amplified noise at 585Hz from the exhaust passageway of a gas turbine was transmitted to the surrounding area through the smokestack.

Threshold for 585 Hz pulsation in the combustion cans is 3-18kpa, rms. When the load rate of gas turbine is 80-95% of full load, the pressure pulsation shows up to >100 pa, rms at the downstream of the diffuser section and has 585 Hz component; then, sound pressure level shows > 101dBA at the top point of the smokestack. It shows that the noise complaints around the power plant are caused by the resonance phenomena in the flue gas passage of gas turbine.

(2) Abnormal sound was transmitted in the mechanism that the standing waves of 585Hz sound field mode at the radius direction of the strut section in an exhaust path was generated by the pulsating pressure at 585Hz transmitted from the combustion cans, and the primarily amplified pulsating pressure at 585Hz in the strut amplified 585Hz's standing wave in circumference direction at the diffuser.

(3) As a measure for noise reduction, the baffle silencer with the sound-absorbing material of the foamed aluminium is applied to isolate the abnormal noise frequency band into the stack; therefore, the measures obtain insertion loss of 20dBA.

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