Vibration Resonance	Strange Sound Occurred on Boiler Exhaust Gas Duct	Plant

Object Machine

Boiler exhaust gas duct (boiler; maximum 12. 6MPa x 533°C, steam flow; 195t/h, electric power generation; 41000kw) (refer to Fig.1)

Observed Phenomena

It was observed that while the boiler load was raised and at about 96% of the rated load, noises (strange sound) with a peak frequency of 30Hz occurred near the primary superheater, but the noises gradually decreased along the gas downstream side. Under the presence of vibrations and noises at 97% load, sound pressure level was measured the boiler width direction at a position in the vicinity of the cross-over duct where go-around is permitted. As a result, it was found that vibration is small in the center and resonance occurred. Also, vibrations are nearly negligible on the downstream side of the expansion joint (Fig.1).

Cause Estimation

Occurrence of vibrations and noises is closely related with the boiler load, and that they suddenly occur when the load exceeds a certain value. It is thus considered that these vibrations and noises are due to resonance between Karman vortex to be generated in the downstream flow of the heat transfer tubes and the air column of the duct. Also, it maybe considered self-excitation sound.

Analysis and Data Processing

(1) Resonance between Karman vortex and heat transfer tubes: Natural frequencies of the heat transfer tubes of both the primary superheater and the secondary primary superheater are 1.7 to 1.8Hz, while the frequency of Karman vortex is about 30 to 40Hz[(1)], that is, they differ to a great extent, thus there is no possibility of resonance.

(2) Air column resonance between Karman vortex and duct: Based on the gap velocity Vg between tubes when vibrations occur (gas flow: 183,000Nm^3/hr) and Strouhal number (St=0.22) of Fizfugh for the tube array, the Karman vortex shedding frequency was obtained to be 35 to 40 Hz for the primary superheater and 31 to 38Hz for the secondary superheater[(1)]. On the other hand, the air column resonance frequency in the width direction of the duct (refer to Fig.2) was calculated by using a sound speed in consideration of temperature and filling rate to be 29Hz for the primary superheater and 34Hz for the secondary superheater[(2)]. Since the frequency of Karman vortex and the natural frequency with the duct are relatively close to each other, it is highly probable that this resonance occurred. As several tube bundle are arranged with a space (cavity) in-between in the duct, an acoustic mode analysis using FEM[(3)] was conducted to find the presence of a resonance mode (30Hz) in question.

Countermeasures and Results

As for this sort of a problem, it is a common practice to insert a baffle plate, so that two baffle plates were inserted (refer to Fig.3.2). During operation to confirm the effect, the noise level was reduced by 5dB, but there still remains the strange sound (103dB(A)). Then, a sound field analysis was conducted with a baffle plate inserted, but the resonance frequency (30Hz) remained almost the same (29.5Hz), with the same mode pattern {compare 1) and 2) in Fig.4}. The above is a proof that the baffle plate has brought no effect, and it is natural that this trial was not effective at all. In his paper[*1], Ishihara states that, since the energy given by the vortex to a sound field is $W=\rho\int(\omega \mathrm{x} V)\cdot \xi dV$, it is necessary to insert such a baffle plate as to reduce a particle speed. Accordingly, a baffle plate was inserted at the center of the duct extending from the primary superheater to the secondary superheater (refer to 3 of Fig.3), with the results given in 3) of Fig.4. As is noticed from this figure, the sound pressure gradient is nearly zero, and a corresponding countermeasure was taken to confirm that no noise occurred at all since then.

Lesson

Insertion of a baffle plate is frequently applied as a countermeasure against air column resonance or aerodynamic self-excited sound. The mechanism of this method is not to avoid resonance by changing the air column resonance frequency, but to modify the local resonance mode, so as to reduce the energy that a vortex gives to the sound field. It is thus important to conduct a sound field analysis and to examine a baffle plate insertion method

to reduce a sound pressure gradient.

References

*1: ISHIHARA, Kunihiko, “Study on strange sounds of a gas superheater having two parallel tube group ducts (Report No.2, Sound attenuation characteristics and its effect of a baffle plate with two holes”, Transaction of the Japan Society of Mechanical Engineers (B) 70-689., pp133-139, (2004-1)

Keywords

Sound Field Control, aerodynamic acoustics, gas heater, duct, baffle plate

Reference data

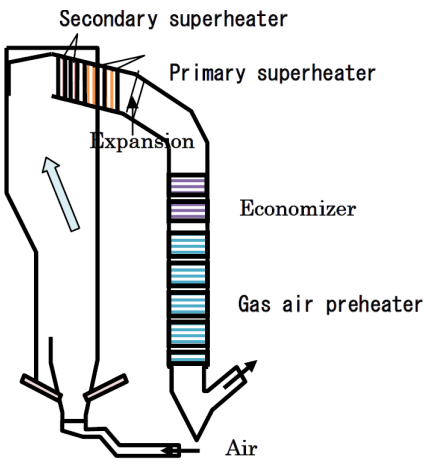
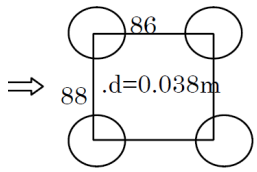


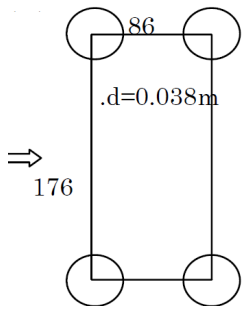
Fig.1 Boiler for power generation

(1) Karman vortex shedding frequency

On the primary superheater:
The tube array is as shown on the right:
T/d=2.3, L/d=2.3
From the tube array: St=0.22
Flow velocity in the tube group gap:
Vg=6-7m/s
Fv=St· Vg/d=0.22x6(7)/0.038=35(41)Hz



On the secondary superheater:
The tube array is as shown on the right:
T/d=4.6, L/d=2.3
From the tube array: St=0.22
Flow velocity in the tube group gap:
Vg=5.5-6.5m/s
Fv=St· Vg/d=0.22x5.5(6.5)/0.038=32(38)Hz



(2) Frequency of air column resonance in duct
.fa=c/2L
Temperature: t=549ºC (primary superheater) - 722ºC (secondary superheater)
Sound speed c_0: 331√(273+t)/273=574m/s (primary) – 632m/s (secondary)
Filling rate: σ=0.15 – 0.037
Effective sound speed c: $c=c_0/\sqrt{1+\sigma}$ =534m/s (primary) – 620m/s (secondary)
Air column resonance frequency fa: 29Hz (primary) – 34Hz (secondary)

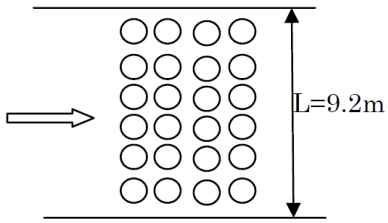


Fig.2 Dimensions of tube group duct

(3) FEM sound field analysis

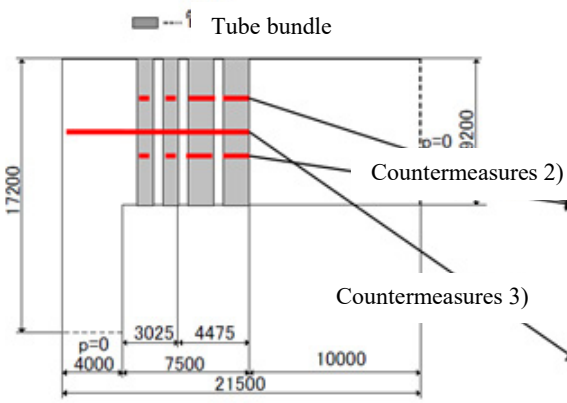


Fig.3 Analysis model

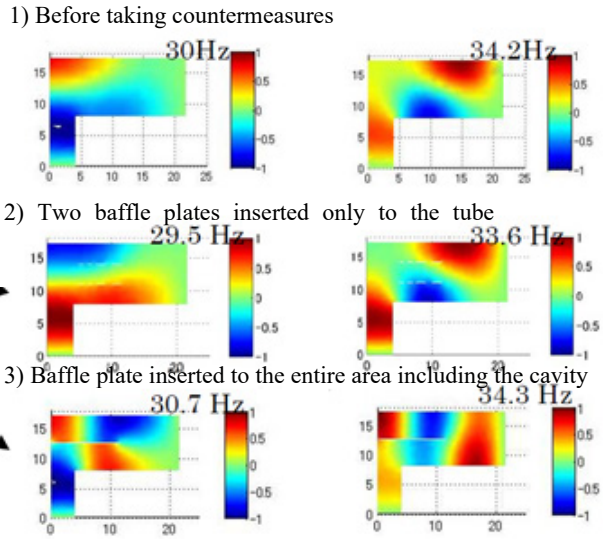


Fig. 4 Result of sound field analysis