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Analysis and Treatment of Flue Duct Vibration of 1000MW Generator Set with High Load

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Abstract. In view of the serious flue duct vibration problem of the outlet of a 1000MW unit with a load of 80%BRL and above, combined the vibration test with the calculation of the acoustic standing wave frequency, the cause of the flue duct vibration was analyzed and determined. A modification plan is proposed to install clapboards to change the standing wave frequency of the flue duct and keep it away from the measured resonance frequency. After the clapboards are installed, the flue duct vibration frequency of the induced draft fan outlet is dispersed from the two main frequencies of 61.3Hz and 61.4Hz before the clapboards were installed to 6.88Hz~204Hz; the maximum amplitude of the flue duct is reduced from 105.0μm to 12.6μm, and the problem of the flue duct vibration is fundamentally solved. This case provides a new idea for solving the problem of vibration of the flue duct in the large-scale power station boiler.

1 Preface

The development direction of high intelligence, large capacity and excellent parameters of power station boilers determines the continuous increase of boiler furnace, flue size and flue gas flow rate. High flue gas flow rate brings frequent occurrence of flue excitation or resonance problems. It not only produces noise pollution to the surrounding environment, but also affects the safe and efficient operation of the unit.

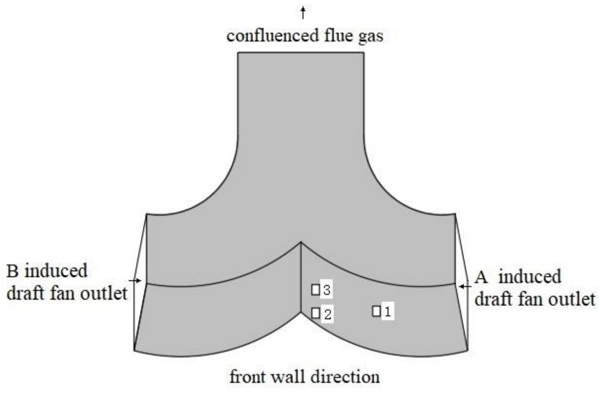
Wu Boyang, Li Youxin, etc.[1]~[3] analyzed the vibration mechanism of the boiler tail flue in detail by combining with the periodic shedding law of the Karman vortex when the high-speed flue gas is subjected to the hot surface tube bundle; Yan Xiaozhong, Yang Guoqi, etc.[4]~[10] analyzed the causes of flue vibration through vibration parameter retrieval and vibration test results; Zhang Huarong, etc.[11] conducted the flue vibration elimination research by optimizing the flue flow field. The researches above put forward differentiated solutions for flue vibration under different conditions, but it is rare to find the root cause of flue excitation or resonance problems by combining vibration testing and flue standing wave frequency calculation.

A HG-2913/29.3-YM2 1000MW coal-fired unit vibrates violently from the outlet of the induced draft fan to the inlet of the desulfurization when it was above 80%BRL load. Flue vibration brings problems such as fan vibration, low temperature gas saver wear and leakage, etc. It also brings threats to the safe, efficient and sustainable operation of the unit.

2 Tests and causes analysis

2.1 Vibration tests

The main design parameters of the boiler is in table 1. To find the vibration causes of the flues from the outlet of the induced draft fan to the inlet of the desulfurization, the vibration test of the flue on the right side of this section was conducted with using SK4432 vibration test analyzer when the unit brings 920MW~930MW load. The test positions is on the measuring hole flange of the flue or on the outer wall of the flue after removing the insulation layer of the flue, which is showed in detail in fig.1, and the results of the test is in the table 3 and and fig.2.



a) the induced draft fan outlet horizontal section

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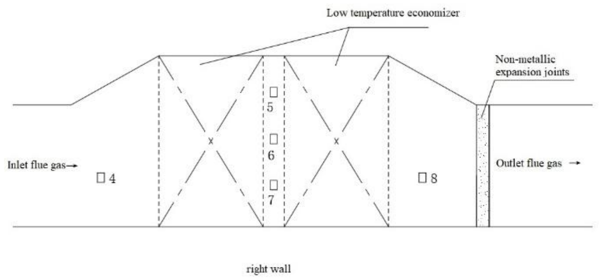

b) the low temperature economizer section

Fig. 1. The vibration test position between the outlet of the induced draft fan and the inlet of the FGD.

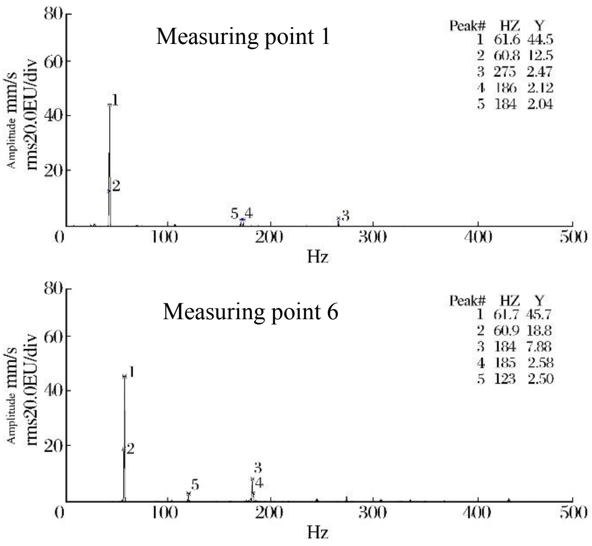

Fig.2. The typical amplitude superimpose in vibration test

Table 1. The main design parameters of the boiler

Name	Unit	BMCR	BRL
Superheated steam mass flow	t/h	2913	2828.2
Superheated steam outlet pressure	MPa(g)	29.3	29.22
Superheated steam outlet temperature	℃	605	605
Reheated steam mass flow	t/h	2384.5	2311.0
Reheated steam inlet pressure	MPa(g)	5.997	5.806
Reheated steam outlet pressure	MPa(g)	5.747	5.565
Reheated steam inlet temperature	℃	360	355.6
Reheated steam outlet temperature	℃	623	623
Feed water temperature	℃	304.9	302.7

According to the vibration amplitude of each part, it is judged that the vibration is mainly concentrated at the outlet of the induced draft fan and the body of the low temperature economizer with the 80% ECR above unit load. The flue vibration frequency falls between 61.3Hz and 61.4Hz, and the maximum amplitude at test position 7 reaches 105μm with the unit load between 920MW and 930MW.

Combined with the dynamic superposition and increase of the vibration amplitude during the test process, it is judged that the large vibration of the flue at the outlet of the induced draft fan was caused by flue resonance.

2.2 Causes analysis

The problems of flue excitation or resonance is partly caused by the integral multiple relationship between the natural acoustic frequency of the flue and the periodic shedding frequency of the Karman vortex generated by the flue gas flow subjected to the hot surface tube bundle (light pipe), the excitation of such vibrations can be attributed to unstable vortex shedding due to the lateral flow of fluid across the sides of a cylinder, which is showed in fig.3; and partly caused by the loose installation or worn of the support or diversion device of the flue.

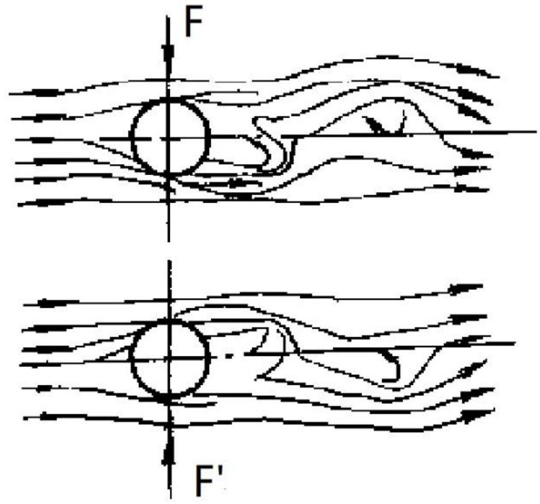

Fig. 3. The karman eddy current

To find the cause of the vibration problem of the flue at the outlet of the induced draft fan with 80% BRL above unit load, the flue natural acoustic frequency's calculation was conducted by calculation equation (1) for the flue with a significantly larger amplitude.

$$f_z = \frac{n}{2}\frac{c}{H} \quad (1)$$

The c in equation (1) is the speed of sound in flue gas medium; n is an integer, which can be 1, 2, 3...; H is the height of the flue itself

The speed of sound in the flue gas medium c at a certain temperature is calculated by equation (2):

$$c = \sqrt{KRT} \quad (2)$$

In equation (2), flue gas adiabatic index K=1.33; gas constant of flue gas R=276J/(kg·K) ; T is the gas thermodynamic temperature.

Combined with the drawings of related equipment and flue, *H* of the horizontal flue at outlet of induced draft fan *is* 7000mm, *H* of the low temperature economizer flue is 12810mm. The average temperature *T* of the horizontal flue at outlet of induced draft fan is 131.25℃ when the vibration tests was conducted at 930MW unit load,which is 130.79℃ at the low temperature economizer.

The second harmonic frequency of the induced draft fan outlet flue's height direction natural acoustic frequency was calculated 55.09Hz by substituting the parameters above into equation (1) and equation (2), similarly, the fourth harmonic frequency of the low temperature economizer flue's height direction natural acoustic frequency is 60.23Hz. The ratio to the measured value 61.30Hz is respectively 0.90 and 0.98.
Research shows that the acoustic resonance of the flue occurs when the ratio k to the natural acoustic frequency's certain order harmonic is 0.8~1.2. In conclusion, the flue vibration at the outlet of the induced draft fan is acoustic resonance when the unit load is 80%BRL above.

3 The solution

To reduce the flue height H can effectively increase the natural acoustic frequency of the flue, so the clapboard installation at the induced draft fan outlet horizontal flue and low temperature economizer flue's height direction is feasible.

According to the flue design drawings of the induced draft fan outlet horizontal flue and the low temperature economizer flue, three 6mm thick and the equal flue gas deflector long clapboards are installed at each induced draft fan outlet horizontal flue as the fig.4 show, and two sets of six 6mm thick rectangular 7850mm × 1625mm clapboards are installed at low temperature economizer's upstream and downstream flue as the fig.5 show. All the clapboards' material is GB700 、 Q235-B ordinary carbon steel.

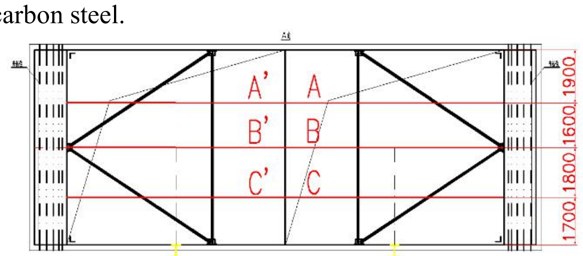

Fig.4. The clapboard installation position schematic diagram of the induced draft fan outlet horizontal fluel

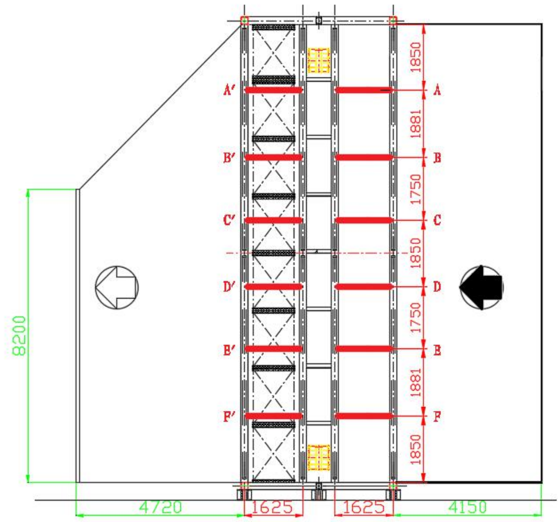

Fig.5. The clapboard installation position schematic diagram of the low temperature economizer flue

In order to avoid the coincidence of the flue natural sound frequencies, the clapboard installation on one side is set differently, which creates hindrance between the adjacent flue.
The calculation result of the each interval flue's natural acoustic frequencies after the clapboard installation is in table 2. From table 2,we can see that the each interval flue's natural acoustic frequencies is above 100Hz after the clapboard installation, which is 1.63 ratio to the measured value 61.30Hz. In part 2.2, we mentioned that the acoustic resonance of the flue occurs when the ratio k to the natural acoustic frequency's certain order harmonic is 0.8~1.2, the ratio 1.63 after the clapboard installation is far away from the acoustic resonance region, which means that the acoustic resonance of the flue will disappear.

Table 2. All the spaced acoustic standing wave theoretical calculation frequency after the clapboards' installation.

Position	Acoustic standing wave frequency(Hz)
Horizontal flue upper wall to upper clapboard	101.49
Upper clapboard to middle clapboard	120.52
Middle clapboard to lower clapboard	107.13
Lower clapboard to horizontal flue lower wall	113.43
Low temperature economizer flue upper wall to the first clapboard	104.17
The first clapboard to the second clapboard	102.46
The second clapboard to the third clapboard	110.13
The third clapboard to the fouth clapboard	104.17

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Position	**Acoustic standing wave frequency(Hz)**
The fouth clapboard to the fifth clapboard	110.13
The fifth clapboard to the six clapboard	102.46
The six clapboard to low temperature economizer flue lower wall	104.17

4 The results before and after the clapboard installation

Considering that the width direction of the flue is too long,the actual clapboards' installation at the low temperature economizer is showed in fig.6.

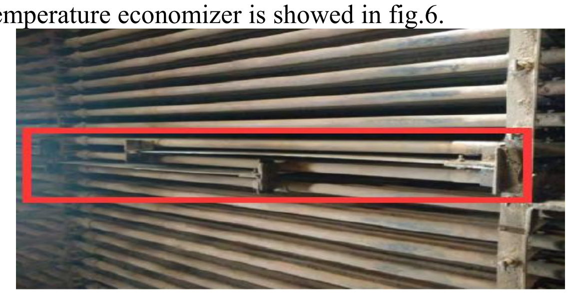

Fig.6. The clapboards' installation at the low temperature economizer on site.

Adopt the solution described in 3 to install the clapboard on the horizontal section of the induced draft fan outlet and the low temperature economizer flue, the flue duct vibration frequency of the induced draft fan outlet is dispersed from the two main frequencies of 61.3Hz and 61.4Hz before the clapboards were installed to 6.88Hz~204Hz; the maximum amplitude of the flue duct is reduced from 105.0μm to 12.6μm, which is showed in table 3.

Due to the vibration frequency and vibration amplitude measurement results of the induced draft fan outlet flue before and after the installation of the integrated clapboard, the problem of the flue duct vibration is fundamentally solved.

Table 3. The contradistinction of the vibration test before and after the clapboards' installation.l

Position		**Amplitude maximum (μm)**		**Frequency at maximum amplitude(Hz)**	
		Before the clapboard installation	**After the clapboard installation**	**Before the clapboard installation**	**After the clapboard installation**
The horizontal section of the induced draft fan outlet	1	60.8	7.11	61.4	6.88
	2	84.1	12.6	61.3	28.8
	3	66.6	12.3	61.3/61.6	19.4
Low temperature economizer inlet	4	25.4	4.21	61.4	204
Low temperature economizer	5	34.6	4.2	61.4	10.0
	6	53.3	5.07	61.4	10.0
	7	**105.0**	2.72	61.4	10.0
Low temperature economizer outlet before expansion joint	8	44.6	9.22	61.4	9.38

5 The conclusion

In view of the serious flue duct vibration problem of the outlet of a 1000MW unit with a load of 80%BRL and above, combined the vibration test with the calculation of the acoustic standing wave frequency, the cause of the flue duct vibration was analyzed and determined. A modification plan is proposed to install clapboards to change the standing wave frequency of the flue duct and keep it away from the measured resonance frequency.

After the clapboards are installed, the flue duct vibration frequency of the induced draft fan outlet is dispersed from the two main frequencies of 61.3Hz and 61.4Hz before the clapboards were installed to 6.88Hz~204Hz; the maximum amplitude of the flue duct is reduced from 105.0μm to 12.6μm, and the problem of the flue duct vibration is fundamentally solved. This case provides a new idea for solving the problem of vibration of the flue duct in the large-scale power station boiler.

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