

Research and application of pneumatic vibration electrostatic precipitator technology for small units of groove plate

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Abstract

The principle of dust escape from the outlet groove plate of the electrostatic precipitator (ESP) was analyzed, and the pneumatic vibration ESP technology for small units of groove plate (SQ-ESP) was developed. By dividing the outlet groove plate of the ESP into small units and setting up a separate vibration for dust removal, its dust collection function was achieved and the bottleneck of secondary dust lifting technology affecting the ESP was solved, achieving the goal of improving the efficiency of the ESP. In December 2023, the ESP of a 630 MW unit in a power plant in Jiangsu Province was renovated and subjected to engineering application tests. The performance was compared under different load using the coal which is difficult to electrostatic precipitator. The test results showed that under full load, the dust concentration at the outlet of the ESP decreased from 25.3–28.6 mg m⁻³ before the renovation to 15.0 mg m⁻³ after the renovation, and the efficiency of the ESP was significantly improved.

Keywords: Dust removal, energy conservation, emission reduction, pneumatic vibration, electrostatic precipitator removal renovation.

1. Introduction

There are over 3000 units of electrostatic precipitators in the market, which are the mainstream equipment for industrial flue gas dust removal. They have the advantages of low pressure loss, no blockage, large amount of flue gas treatment, simple operation and maintenance, and high dust removal efficiency. Around 2010, China's standards required dust emissions to be less than 30 mg m⁻³. At that time, the dust concentration at the outlet of domestic electrostatic precipitators was generally around 50 mg m⁻³. The main technologies used for transformation were electric field expansion, moving electrodes, and electric bags. In 2014, with the implementation of ultra-low emissions from coal-fired power plants in China, the dust concentration at the outlet of electrostatic precipitators was required to be 15–20 mg m⁻³. Low temperature electrostatic precipitator retrofitting began to be widely applied, and the dust concentration at the outlet of electrostatic precipitators could reach below 15 mg m⁻³ [1]. Related studies have shown that secondary dust is the main reason for the dust concentration exceeding 10 mg m⁻³ at the outlet of electrostatic precipitators [2–5].

At present, a large number of low and low temperature electrostatic precipitators in China have been used for nearly 10 years. With the passage of operating time, the flue gas cooler at the front end of the electrostatic precipitator has started to suffer from outlet wear and leakage problems, and some power plants have removed the flue gas cooler [6]. The 14th Five Year Plan for Modern Energy System in 2022 proposes to achieve a flexible regulation of 24% of power sources by 2025 to promote the consumption of clean energy [7, 8]. The frequency and amplitude of coal-fired power units participating in peak shaving continue to increase, and multi coal and variable load ultra-low emission technologies need further in-depth research. In this context, the market urgently needs new electrostatic precipitator technologies with simple operation and maintenance, good

adaptability to transformation, strong load adaptability, low transformation cost, and high dust removal efficiency.

Due to the need to improve the efficiency of a large number of on-site electrostatic precipitators in China and within a certain time frame, as well as site limitations, there is an urgent need to develop new technologies for improving the efficiency of electrostatic precipitators to further reduce environmental dust emissions. SQ-ESP can be modified in conventional electrostatic precipitators, with the advantages of low modification cost, short modification time, no occupation of space, and significant efficiency improvement. In depth research and promotion of SQ-ESP are of great significance for improving the efficiency of electrostatic precipitators.

2. The pneumatic vibration ESP technology for small units of groove plate

2.1 Analysis of bottlenecks in electrostatic precipitator technology

With the development of low temperature electrostatic precipitators, co firing of coal with sludge, and the changing global energy landscape leading to the widespread combustion of low-quality coal with high moisture and sulfur content in China, the adhesion of dust inside electrostatic precipitators has significantly increased, and the problem of ash sticking on the outlet airflow distribution board has become increasingly serious [9, 10]. The collection and cleaning of ultra-fine dust at the tail of an electrostatic precipitator is the most concerned issue in the dust removal field. It is the last checkpoint and barrier, and the dust collection problem of the outlet horn is the last barrier of dust removal technology.



Fig. 1. Conventional groove plates and accumulated dust.

2.2 Dust collection principle of SQ-ESP

The conventional outlet groove plate of electrostatic precipitator improves the uniformity of airflow in the electric field of the electrostatic precipitator by blocking, with only the effect of airflow uniformity. The dust in the flue gas is negatively charged under the corona discharge effect in the electric field, and most of it is captured by the anode plate under the electric field force. A small amount of dust is carried back into the flue gas by the airflow during the vibration cleaning process, forming secondary dust.

Most of the dust entering the outlet head of the electrostatic precipitator carries negative charges and adheres to the outlet distribution plate. As the thickness increases, due to the electrical resistance of the dust, the charge on the dust cannot be released through the groove plate after the dust layer reaches a certain thickness. A negative voltage is formed in the space of the groove plate, forming a reverse electric field force, which causes the dust in the flue gas to no longer adsorb to the groove plate, thus causing the groove plate to lose its dust collection function. The principle that conventional groove plates cannot collect dust is shown in Fig. 2. Does the surface charge of the dust layer imply a repulsive force of the same charge on the flying dust, preventing the dust from adsorbing onto the groove plate and causing the groove plate to lose its ability to adsorb dust again.

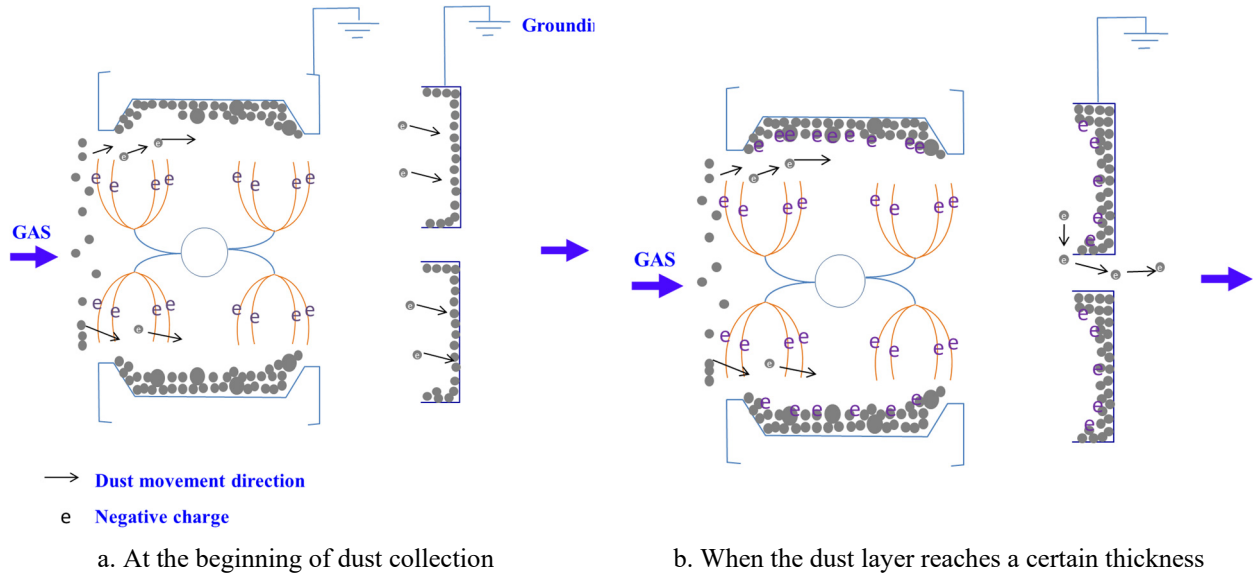


Fig. 2. Principle diagram of conventional groove plate unable to collect dust.

A SQ-ESP was designed [11], as shown in Figs. 3–4. The outlet groove plate of the electrostatic precipitator was divided into small units and a separate vibration dust removal was set up. When the dust on the groove plate reached a certain thickness, the dust layer was removed by vibration, thereby blocking the formation of reverse voltage. The dust in the flue gas can be adsorbed onto the groove plate again, achieving the continuous dust collection function of the groove plate. On the other hand, due to the fact that the vibration of the groove plate cannot avoid the formation of a certain amount of secondary dust, setting up small units can effectively avoid the peaks of secondary dust, and the vibration force can be more uniform and effective, thereby reducing secondary dust.

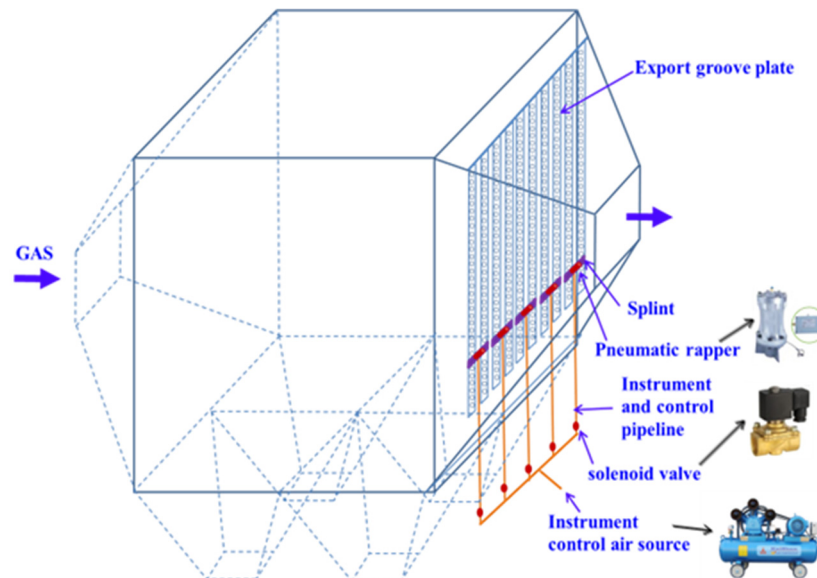


Fig.3. Three-dimensional schematic diagram of SQ-ESP.

The operating parameters of the pneumatic rapper mainly include: air source pressure of 0.3–0.7 Mpa, air consumption of 0.15–0.36 L/time, vibration impact force of $24.5\text{--}38.0 \text{ N}\cdot\text{M s}^{-1}$, maximum striking force of 3.0–5.0 tons, and aluminum alloy shell material. Each pneumatic rapper is controlled to start and stop by an electromagnetic gas, and the vibrators are staggered according to pre-set logic to reduce secondary dust and instantaneous gas consumption. The pneumatic rapper is sealed and isolated from the smoke environment to avoid dust and corrosive gas, thereby improving its service life.

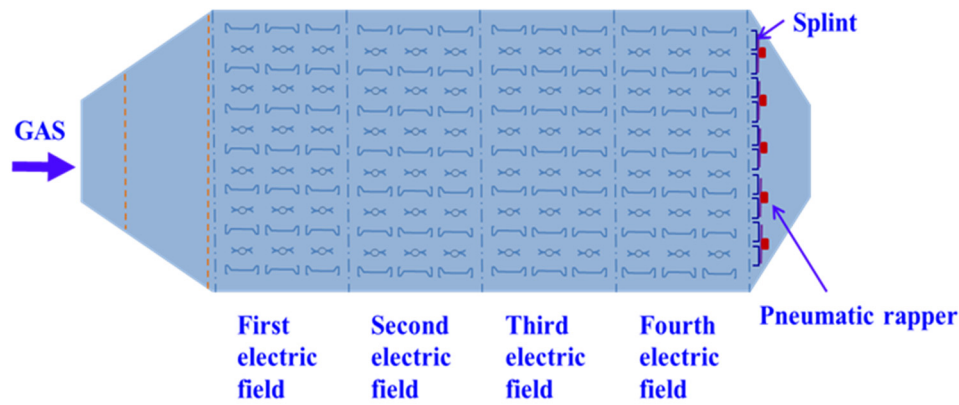


Fig. 4. Principle diagram of SQ-ESP.

2.3 Principle of pneumatic rapper

Pneumatic rapper is a commonly used rapping equipment in industry, and its principle is shown in Figure 5. When no compressed air is introduced, the magnetic piston is attached to the fixed plate due to magnetic force. The compressed air flows into the rapper through the electromagnetic valve control instrument and increases the pressure. When the pressure exceeds the magnetic force, the piston quickly detaches from the fixed plate, generating a strong counterattack force under the reaction force of the magnetic force. The high-speed falling piston collides with the fixed plate, transmitting the impact force. The vibration interval time and striking force can be adjusted through electromagnetic valves and instrument air pressure [12, 13].

When the solenoid valve stops powering on and compressed air enters, the compressed air inside the rapper is discharged. Under the action of spring force, the piston slowly rises and under the action of magnetic force, it adsorbs onto the fixed plate and returns to its initial state [14, 15].

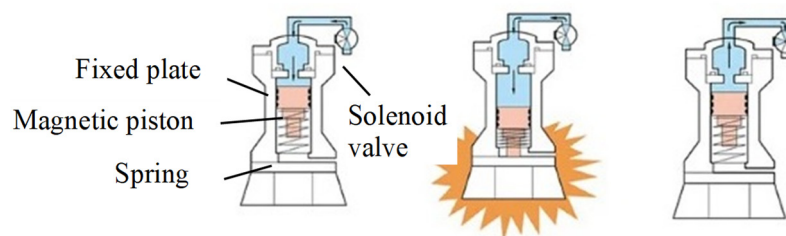


Fig. 5. Plan schematic diagram of small unit pneumatic vibration ESP [16].

2.4 Vibration logic of small unit pneumatic vibration

To reduce the secondary dust caused by vibration and minimize the overlap between them, the layout of the vibration device that needs to be controlled is shown in Fig. 6. The vibration control logic is set as follows:

- When the front electric field of the same chamber is used for dust cleaning, the pneumatic vibration of the small units of the outlet distribution board downstream of the same chamber is not carried out, and the control logic is set to staggered vibration for dust cleaning.
- The same indoor small unit is vibrated by different pneumatic vibrators at the same time.
- The interval time for vibration can be set to a fixed time based on the dust collection situation, or a differential pressure gauge can be set before and after the vibration can be carried out when the set pressure difference reaches a certain limit.

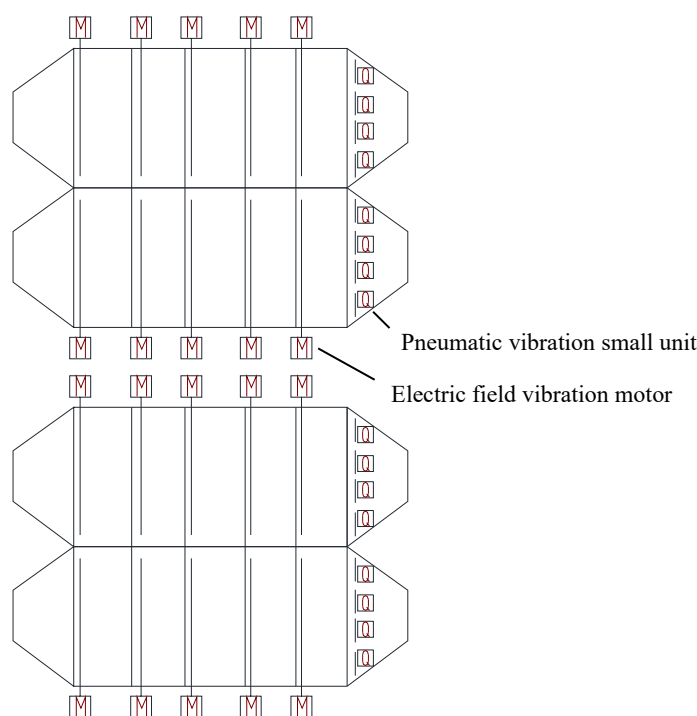


Fig.6. Vibration position of SQ-ESP.

3. Electric dust removal renovation of 630 MW units in coal-fired power plants

3.1 Necessity analysis of project renovation

In 2013, the electrostatic precipitator of a 630 MW coal-fired power generation unit in Zhenjiang, Jiangsu Province underwent a mobile electrode transformation on the fifth electric field. After the transformation, the electrostatic precipitator ensured that the outlet dust concentration was less than 40 mg m^{-3} . After 10 years of operation, the failure rate of the mobile electrode plate has increased, which cannot meet the requirement of no more than 10 mg m^{-3} of smoke and dust emissions in key areas specified in GB13223-2011 Air Pollutant Emission Standards for Thermal Power Plants.

As the main equipment for dust removal, only by reducing the dust concentration at the outlet of the electrostatic precipitator and then collaborating with downstream wet flue gas desulfurization can the smoke and dust emissions meet the standard requirements.

3.2 Performance analysis before project renovation

A preliminary test was conducted on the electrostatic precipitator. When the unit load was 600 MW and the main steam flow rate was $1750 \text{ ton} \cdot \text{h}^{-1}$, the inlet concentration of the electrostatic precipitator was $18.4\text{--}19.5 \text{ g m}^{-3}$, and the outlet dust concentration was $25.3\text{--}28.6 \text{ mg m}^{-3}$. The inlet smoke temperature of the electrostatic precipitator was $107.5\text{--}115.8 \text{ }^{\circ}\text{C}$, and the air leakage rate of the dust collector body was $0.42\text{--}2.01\%$. The inlet flue gas flow rate of each chamber is $784626\text{--}860844 \text{ m}^3 \text{ h}^{-1}$, with a total flue gas volume of $3266086 \text{ m}^3 \text{ h}^{-1}$ (equal to $907.25 \text{ m}^3 \text{ s}^{-1}$). The oxygen content at the inlet of the dust collector is $3.72\text{--}5.80\%$, and the velocity and temperature fields of the inlet flue sections of the four chambers of the dust collector are relatively uniform.

3.3 Small unit pneumatic vibration transformation

A small unit pneumatic vibration transformation was carried out on the electrostatic precipitator of a 630 MW coal-fired power generation unit in Zhenjiang, Jiangsu, as shown in Figs. 7 and 8, and the photo be taken from direction of Fig. 7 as show in Fig. 3. The moving electrode electric field of the fourth electric field was also transformed into a fixed electrode electric field.



Fig.7. Small unit pneumatic vibration device

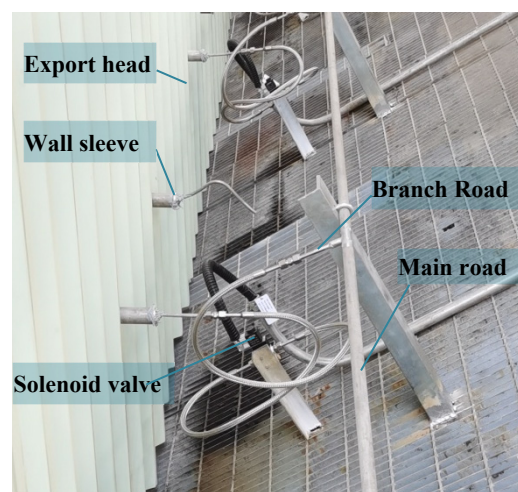


Fig.8. Control pipelines and valves.

3.4 Operating conditions during performance testing after renovation

The main technical parameters before and after the renovation of the electrostatic precipitator for the 630 MW coal-fired power generation unit in Zhenjiang, Jiangsu are shown in Table 1. The coal composition of the coal used in this project was analyzed, as shown in Fig. 9. The coal composition of this project has a high water content, which is generally manifested as high moisture content and high viscosity in the ash in the electrostatic precipitator, making it difficult to clean the ash. The legends indicate the mass fractions, Car is carbon, Har is Hydrogen, Sar is Sulfur, Oar is Oxygen, Nar is Nitrogen, Aar is ash and Mar is moisture.

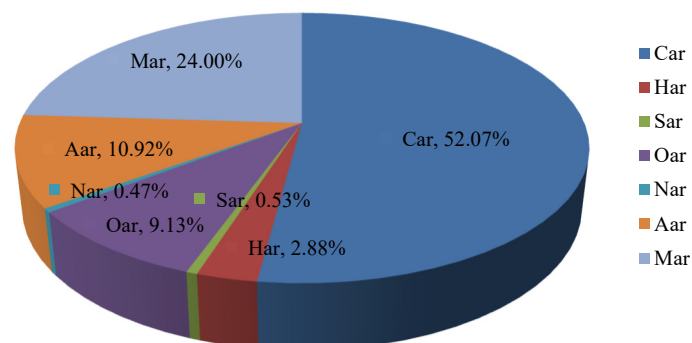
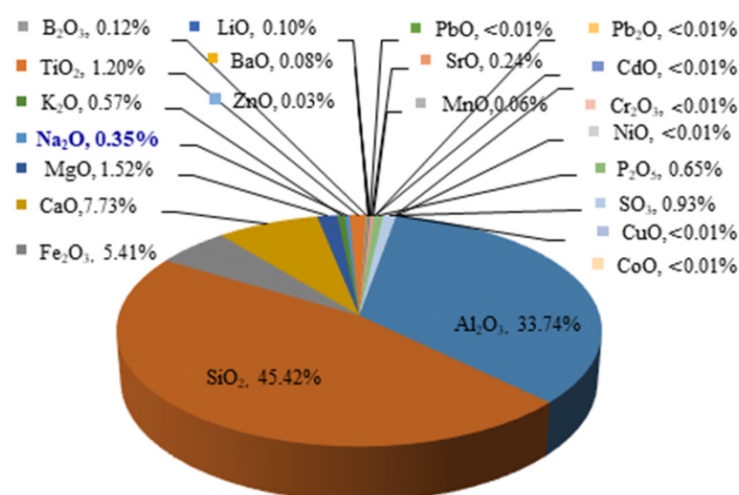


Fig.9. Coal composition.

Table 1. Main technical parameters of 630 MW unit in Zhenjiang power plant in Jiangsu province.

Item Fig.3	Parameter	
	Before renovation	After renovation
Export groove plate	Fixed groove plate	Small unit pneumatic vibration dust collection device
Number of distribution dust collectors per furnace	Two dual chamber four electric fields	Two dual chamber four electric fields
Ensure dust removal efficiency%	99.5	99.86
Design of electrostatic precipitator to ensure dust concentration at the outlet mg m^{-3}	≤ 40	≤ 28
Specific dust collection area $\text{m}^2 \cdot (\text{m}^3 \text{s}^{-1})^{-1}$	Fixed electrode 89.7 Mobile electrode 15.9	114
High voltage power supply	Power frequency power supply: 1.5A/66 kV	High frequency power supply: 2.2A/72 kV
Same pole spacing		405 mm
Design inlet flue gas temperature		$110 \pm 10 \text{ }^\circ\text{C}$
Body air leakage rate		$< 2\%$
Body pressure drop		$< 290 \text{ Pa}$

An analysis was conducted on the fly ash from coal combustion in this project, and the ash composition is shown in Fig. 10. From the ash composition analysis results, it can be seen that Na_2O in the ash is only 0.35%, which is lower than the importance index of 0.5% [17, 18]. Therefore, the ash composition shows that its electrostatic precipitator effect is poor, which is not conducive to electrostatic precipitator and belongs to the difficult to collect dust type.

**Fig.10.** Ash composition.

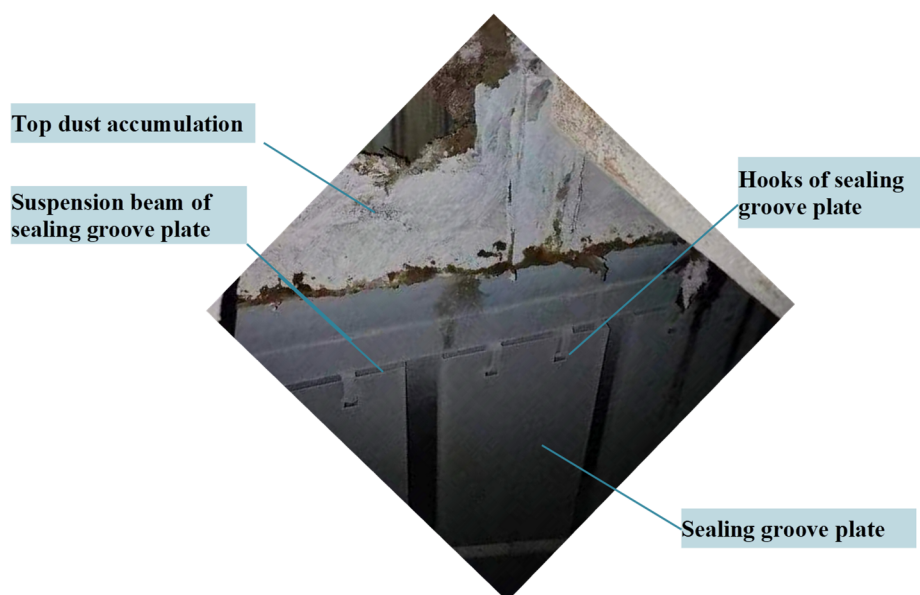
The operating parameters of the high-voltage power supply for this project are shown in Table 2, and each electric field is operating normally and has been debugged to the optimal state.

Table 2. Operating parameters of high-voltage power supply for ESP of 630 MW unit in Zhenjiang power plant in Jiangsu province.

	First electric field		Second electric field		Third electric field		Fourth electric field	
	Secondary voltage/kV	Secondary current/mA	Secondary voltage/kV	Secondary current/mA	Secondary voltage/kV	Secondary current/mA	Secondary voltage/kV	Secondary current/mA
Chamber 1	54	535	56	612	53	394	51	412
Chamber 2	52	586	52	545	48	416	54	523
Chamber 3	45	475	53	397	53	503	45	463
Chamber 4	48	543	52	452	31	458	57	536

3.5 Analysis of shutdown after six months of operation

After six months of project operation, routine shutdown maintenance was carried out, and the outlet groove plate was suspended. The ash accumulation situation of the outlet groove plate is shown in Fig. 11. From on-site equipment maintenance, it was found that there was almost no dust accumulation on the outlet groove plate. In contrast, there was significant dust accumulation on the sealing plate without vibration on the upper part of the outlet head. The comparison shows that the use of a small unit pneumatic vibration device on the outlet groove plate can effectively achieve dust removal, and the entire device operates well.

**Fig.11.** Photo of the sealing groove plate at the export end after six months of operation.

4. Performance comparison test of 630MW coal-fired unit after ESP transformation under different loads

Using the testing methods specified in relevant standards, the inlet of the electrostatic precipitator is subjected to high dust concentration flue gas conditions. The testing method applicable to high dust concentration, GB/T16157 "Measurement of particulate matter and sampling of gaseous pollutants in exhaust from fixed pollution sources", mainly using sampling guns and fiberglass filter cartridges, is adopted. The outlet of the electrostatic precipitator is a low dust concentration flue gas working condition, using the "Fixed Source Emission - Determination of Mass Concentration of Low Concentration Particles (Dust) - Manual Gravimetric Analysis Method" ISO 12141 [19–22], mainly using a low concentration sampling gun and quartz filter

membrane. After stable operation of the unit load for 2 hours, sample the electrostatic precipitator for 60 minutes. Sampling time is more than one vibration cycle of the electrostatic precipitator.

In 2023, the electrostatic precipitator of the 630 MW unit at Zhenjiang Power Plant in Jiangsu Province was renovated. The test results under different loads are as follows [23]:

- a. Under the load condition of 603 MW, the flue gas inlet flow rate is $2434360 \text{ m}^3 \text{ h}^{-1}$, and the dust concentration at the outlet of the electrostatic precipitator is reduced from $25.3\text{--}28.6 \text{ mg m}^{-3}$ before the renovation to 15.0 mg m^{-3} after the renovation.
- b. Under the load condition of 474 MW, the flue gas inlet flow rate is $1047707 \text{ m}^3 \text{ h}^{-1}$, and the dust concentration at the outlet of the electrostatic precipitator is 4.77 mg m^{-3} .
- c. Under the load condition of 315 MW, the flue gas inlet flow rate is $778035 \text{ m}^3 \text{ h}^{-1}$, and the dust concentration at the outlet of the electrostatic precipitator is 11.84 mg m^{-3} .

Through comparative testing of different loads, it was found that the small unit pneumatic vibrating electrostatic precipitator has good adaptability to load changes and has achieved low outlet dust concentration. On the other hand, due to the decrease in load, the amount of flue gas decreases, the flow rate of flue gas decreases, and the dust concentration at the outlet of the electrostatic precipitator correspondingly decreases.

The pneumatic vibrator is installed on the traditional groove plate, but the fixing method of the groove plate has been changed from fixed before the transformation to upper suspension and lower limit. From the above test data, it can be seen that when the air volume decreases or the dust removal area increases, the pneumatic vibration transformation of the slot plate small unit can achieve 4.77 mg m^{-3} . Therefore, it is speculated that after increasing the dust collection area of the electrostatic precipitator body, the pneumatic vibration transformation of the slot plate small unit can achieve less than 10 mg m^{-3} . Excluding other factors, it is estimated that this technology has reduced the dust concentration at the outlet of the electrostatic precipitator by about 10 mg m^{-3} under this engineering condition.

6. Conclusion

The obtained main results in this work can be summarized as follows.

- a. The performance indicators of electrostatic precipitators in China have reached the international leading level, but there are still bottlenecks such as large volume and high steel consumption under the same performance requirements. Miniaturization and efficiency are the inevitable development direction of electrostatic precipitators in market competition.
- b. SQ-ESP has the advantages of significant system, strong adaptability for transformation, and low cost. Under the current higher environmental requirements, it can meet the existing electrostatic precipitator transformation needs of coal-fired power plants and non-electric industries and can be used as a choice for the transformation of existing electrostatic precipitators and bag filters.
- c. With the arrival of the overhaul period of electrostatic precipitators after ultra-low emission construction and the implementation of energy-saving and carbon reduction policies, a large number of dust collectors in China are about to undergo overhaul and renovation. The SQ-ESP of the 600 MW unit of Zhenjiang Power Plant in Jiangsu Province has reduced the dust concentration at the outlet of the electrostatic precipitator from $25.3\text{--}28.6 \text{ mg m}^{-3}$ before the renovation to 15.0 mg m^{-3} after the renovation, while burning difficult to collect dust coal at full load.
- d. Recently, pneumatic vibration technology has been widely applied to anode plates and cathode wires to solve the problems of sludge co combustion, ammonium bisulfate escape, and ash accumulation caused by the use of inferior coal. It aims to improve the minimum vibration acceleration of the anode plates and cathode wires of electrostatic precipitators and enhance the uniformity of vibration acceleration distribution. At present, it has been installed in the 1000MW unit of *Jiaxing* power plant in China. After the technology matures in the future, due to the advantages of flexible layout and small space occupation of pneumatic vibration technology, it can further improve the efficiency of electrostatic precipitator, reduce land occupation and equipment costs, and has obvious promotion prospects.

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References

- [1] Yu G., Liu K., Hu Z., Zhang T., and Liu N., Deep peak shaving optimization scheduling of thermal power units under large-scale new energy grid connection. *Electric Power Eng. Technol.*, Vol. 42 (1), pp. 243–246, 2023.
- [2] Zhao H., Li J., He Y., and Yao Y., Research and application of low and low temperature key technologies, *China Electric Power*, Vol. 47 (10), pp. 117–120, 2014.
- [3] Misaka T., Mochizuki Y., Recent application and running cost of moving electronics type electrical predictor. *11th International Conference on Electrical Precision.*, pp. 518–522, 2008.
- [4] Zhao H., Construction of a rotating electrode electrostatic precipitator cleaning brush test device. *Light industrial machinery*, Vol. 33 (1), pp. 92–97, 2015.
- [5] Liu B., Zheng Q., Gao C., Du C., Wang S., Li S., Zhang J., Bao T., Yang Y., Wang J., Han P., and Yan K., Emission reduction and energy saving of electrostatic precipitation used for coal-fired boilers. *Int. J. Plasma Environ. Sci Technol.*, Vol. 11 (2), pp.165–199, 2018.
- [6] Ouyangzi D., Wang H., Lv Q., Zhu S., Zeng Z., Progress in deep peak shaving technology for coal-fired boiler generator units, *Chinese J. Elect. Eng.*, Vol. 2 (2), pp. 1–10, 2023.
- [7] Zhao H., He Y., Zhang Y., Zhan L., and Guo Y., Research on adaptability of low and low temperature electrostatic precipitator under complex and variable working conditions, *Environ. Eng.*, Vol. 36 (6), 4, 2018.
- [8] Liu Hanxiao Energy saving and carbon reduction analysis of electrostatic precipitators under dual carbon background, *Power Generation Technol.*, Vol. 44 (5), pp. 738–744, 2023.
- [9] Liu H., Luo S., Yu L., Liang J., Guo Y., Cui Y., Shan S., Liu X., and Li J., Study on multi-pollutant test and performance index determination of wet electrostatic precipitator, *Partitions*, Vol. 10 (536), pp. 1–17, 2023.
- [10] Zhao H., Yang G., Shen J., Liu B., and Lu Z., Research on the shielding effect of the electronic frame in the electronic precision, *J. Air Waste Manag. Asso.*, 73 (6), pp. 1–10, 2023.
- [11] Zhao H., He Y., Liang Jiang L., Liu H., and Luo J., A small unit pneumatic vibration guide dust collection device for electrostatic precipitator outlet: 2023110013685, 2023.
- [12] Zhang J., Zhang J., Zhang J., and Wu X., A new type of pneumatic hammer device: CN-A-203390894U. 2014.
- [13] Bao Wenlong Pneumatic hammer type anode vibration device: CN-A-114029168A, 2024.
- [14] Wang Zhanshan, Pan Libo. Numerical simulation study on the implementation effect of air pollutant emission standards for thermal power plants, *Environ. Sci.*, Vol. 35 (3), pp. 853–863, 2014.
- [15] Zhang X., Simulation of reducing residual stress in laser cladding by hammering method and development of hammering system, *Suzhou University*, 2019.
- [16] Li Y., Zhu Y., and Tong Z., Improvement of pneumatic shock absorbers to solve the problem of poor cement cutting, *General Machinery*, Vol. 2, pp. 61–63, 2016.
- [17] Zhao H., Qian S., He Y., Xu Y., and Wang F., Analysis and engineering application of electrostatic dust removal characteristics of coal fired smoke in Vietnam, *Electricity and Energy*, Vol. 44 (4), pp. 395–400, 2023.
- [18] Electric Dust Removal Committee of China Environmental Protection Industry Association. Design Guide for Selection of Electric Dust Collectors. *China Electric Power Press*, 2013.
- [19] State Environmental Protection Administration. GB/T16157-1996 Determination of particulate matter and sampling method for gaseous pollutants in exhaust from fixed pollution sources. *China Standards Press*, 1996.
- [20] Science and Technology Standards Department of the State Environmental Protection Administration. HJ/T397-2007 Technical Specification for Fixed Source Exhaust Gas Detection. *China Environmental Science Press*, 2007.
- [21] National Technical Committee for Standardization of Environmental Protection Industry. GB/T 13931-2017 Performance Test Methods for Electrostatic Precipitators. *China Standards Press*, 2017.
- [22] IX-ISO-ISO 12141-2002 Stationary Source Emissions Determination of Mass Concentration of Particle Matter (Dust) at Low Concentrations Manual Gravimetric Method. 2002.
- [23] Qingdao Huafeng Weiye Electric Power Technology Engineering Co., Ltd Performance Test Report on Electric Dust Removal for Unit 5 of Zhenjiang Power Plant in Jiangsu Province. Qingdao: Qingdao Huafeng Weiye Electric Power Technology Engineering Co., Ltd., 2023.