Design and performance evaluation of a small unipolar aerosol charger system

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Abstract. A small unipolar aerosols charger system is designed by using corona discharge technology. The performance is evaluated and calibrated in this paper. This system has two main components, one is the corona discharge which adopt tip - arc structure, and the another is high voltage constant current control circuit based on the weak current feedback adjustable as the corona current control part, which ensure that ion concentration remain stable in the process of discharge. The experimental results show that negative corona discharge is better than the positive corona discharge in the same discharge corona current. The intrinsic charging efficiency get better with corona current increases, which can as high as 99% when the negative discharge corona current is 3 µA. However the extrinsic charging efficiency change with corona current change, it got the best performance in the corona current 1.5µA at different particle size in this paper. This small and simple design of the unipolar charger system is suitable for portable aerosol classifier based on electrical mobility techniques.

1. Introduction

The traditional method to measure the particle number concentration adopt aerodynamic flight time measurement method [1] or light scattering method[2], these methods are difficult to accurately detect the nanoparticles under 300 nm. However there is no theoretical lower limit if base on particle electrical mobility techniques, it is high accuracy and good real-time performance, thus this method gradually becomes the international mainstream nanoparticles detection method. As the main part of this method, the intrinsic and extrinsic charging efficiencies of the charger will ultimately affect nanoparticles concentration of inversion, which will influence the detection precision of nanoparticles. Therefore, high-performance charger has a great impact to the detection precision of nanoparticles number concentration.

Instrument manufacturers generally adopt bipolar radioactive source as aerosol charger, the particles stay a sufficient time in charger to bring the charged particles into charge balance [3]. Its charging efficiencies depends on the source intensity, ion rate and system structure [4]. In all the bipolar chargers, the neutral particles can acquire charge while the charged particles may discharge

themselves by capturing ions of the opposite polarity, so bipolar charging efficiencies is lower than unipolar. The measurement accuracy of aerosol monitor using bipolar radiation source as a neutralizer is relatively low when particle concentration is dilute.

There are many researchers use corona discharge as ion source [5-6], C. L. Qi adopted electric migration method to design a unipolar charger through electric field migration to electrical charge. Corona discharge was mainly used for electrostatic dust removal technology in China [7], T. L. Zhu used dc corona discharge to remove indoor air microbial and particulate matter [8]. However C. L. Qi's charger structure is complex, it is not easy to manufacture and installation. In this paper, a simple tip - arc discharge structure and dual channel flow is designed. Compared with bipolar chargers the unipolar chargers do not happen bipolar charged particle becomes to neutral particles by capturing ions of the opposite polarity, the control circuit in constant current mode to improve the stability of corona discharge, remain stable charging efficiencies.

2. Design and experiment

The small unipolar aerosol charger system has two parts, one is charger of corona discharge, and the other is high voltage constant current control circuit to provide stable high voltage constant current for the charger.
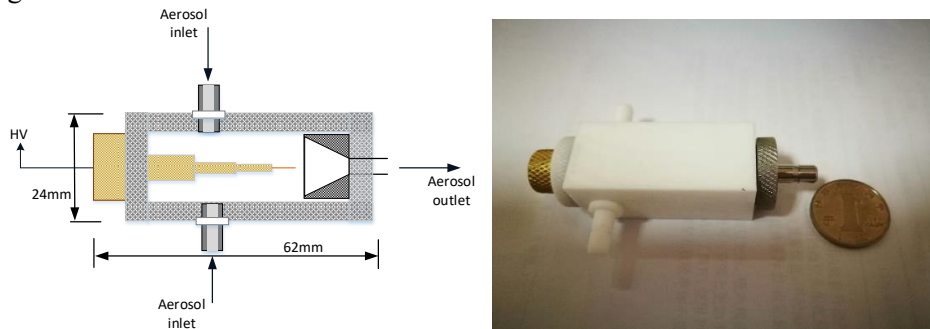

Figure 1. The structure of small unipolar aerosol charger and picture

The charger structure model is shown in figure 1, the tip-arc discharge structure was adopted to easier corona discharge, the distance between the discharge needle and the arc is equal, and electric field was relatively uniform, so charged particles were difficult to happen electrostatic deposition. Air from two channels into the charger at the same time, finally out on arc side, the overall flow is relatively flat, can be spread evenly charged. Overall size is 62mm × 24mm × 24mm rectangle structure, which the needle have three layer structure, its tip is pure platinum materials of 0.05 mm diameter.
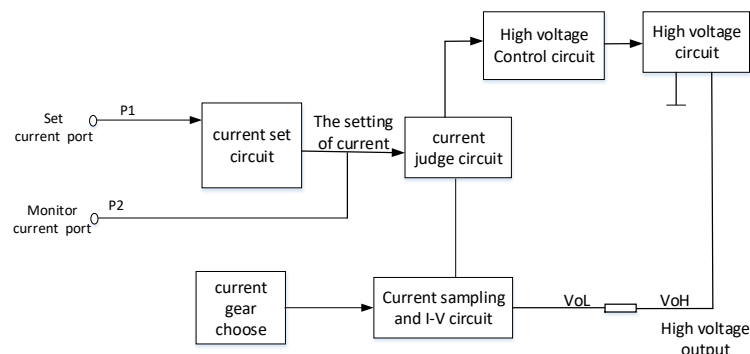

Figure 2. The principle diagram of high voltage constant current control circuit

In order to make the charger discharge state more stable, the high-voltage constant current circuit control system was designed as shown in Figure 2. Select the appropriate gear by setting the current gear choose，then set the required current value. After the high voltage circuit is started, the high voltage module is driven by the high voltage control circuit, and the output voltage rises. The current

value is discrimination by the current judge circuit, if the current value is less than the set value, it is necessary to continue to increase the voltage. Otherwise, the high voltage module will be controlled to reduce the output voltage until the set current value is reached.

The influence factors of diffuse charge mainly have two main in the scope of the sub-micron and nanometer level, one is charger internal corona discharge ion concentration, and the other is the time duration of the particles inside the charger [9]. Charger internal ion concentration depends on the tip of corona discharge current [10]. It can be controlled by high voltage constant current circuit. Particle in the charger retention time is controlled by the airflow velocity. The higher ion concentration, the greater the intrinsic charging efficiency of the charger, but will result in more charged particle losses due to increased space charge effects [11]. So it is not possible to simply increase the extrinsic charging efficiency by increasing the discharge corona current of the charger.

On the one hand, increasing the corona current can increase the ion concentration inside the charger, the probability of charged increases and the number of charge increases. However, if the corona current is increased, a higher corona voltage is required to increase the internal field strength of the charger. The electrostatic loss increases with the internal electric field increasing. Therefore, it is the necessary to assess the performance of charger in different polarity, different corona current conditions by measuring the total particles charge.

The corona current evaluation calibration system of the charging system is shown in Figure 3, through the high voltage constant current control circuit set the charger discharge corona current value. When the charger is in the discharge corona state, total particles charge is measured by the aerosol electrometer after the particles charged. During the test time, the concentration and particle size distribution of the laboratory air particles remained unchanged, and the flow rate of the air flow was kept constant. The discharge corona current of the charger was adjusted by controlling the constant current source to obtain the maximum total particles charge, at which time the corona discharge current is the preselected current of the discharge corona current of the charger system.
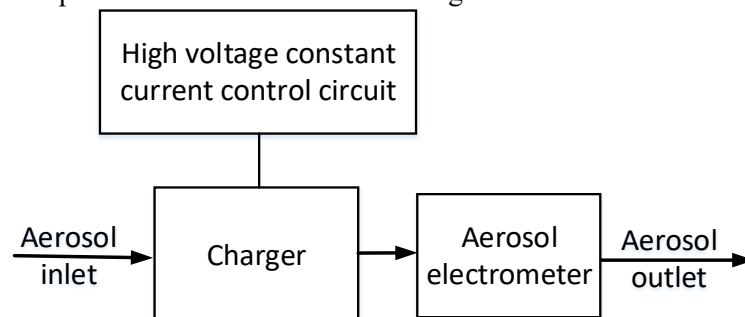

Figure 3. The evaluation calibration system principle diagram of corona current

Experimental results are shown in figure 4, the experiment tested various corona current in positive corona discharge and negative corona discharge. The results show that the charge of particles increases rapidly with the increase of corona current in the discharge corona current is small, then remain unchanged, the charge of particles there is a decline in the process with the discharge of corona current increases until achieve a certain corona current. The total particles charge after the charger reaches the highest state when corona current reaches 4μA in the positive corona discharge or reaches 3μA in the negative corona discharge. In the same corona current, negative corona discharge of the total particles charge significantly better than positive corona discharge, which means that the negative corona discharge effect is better than positive corona discharge.
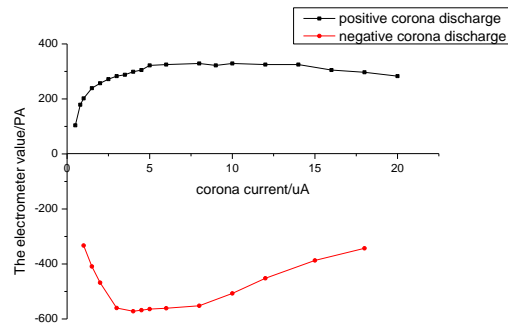
Figure 4. The current values of detection with different corona currents

The main factors of the total particles charge are number concentration of export particle and its average charge. Diffusion movement and electrostatic interaction is the main factors to concentration of particles, ions concentration in the charger and the space charge effect is the main factors to the average charge of particles.

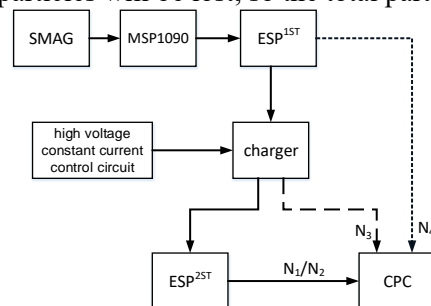Particle saturation charge in the case of diffusion charging is given by: [12]

$$q = e \cdot \frac{2\pi\varepsilon_0 kT d_P}{e^2} \ln(1 + \frac{e^2 \bar{u} d_P N_0 t}{8\varepsilon_0 kT}) \qquad (1)$$

Where k is the Boltzmann constant, $1.38{\times}10^{-23} J / K$; T is the gas temperature; N_0 is the ion concentration, number / m^3; e is the electron charge; $\bar{u}$ is the average of the gas ions Thermal velocity; ε_0 is the vacuum dielectric constant; d_P is the particle size of the particles.

The electric field force of the particles is given by:

$$F = Eq \qquad (2)$$

From the equation (1) we can know that the total particles charge is proportional to the particle size and the total particle charge increases with increasing particle size. However, the number of the particle charge will be more along with the increase of the particle size, then getting larger electrostatic force and the more particles will be lost, so the total particles charge is affected.

SMAG: sub-micrometer aerosol generator; ESP: electrostatic precipitator; CPC: condensation particle counters
Figure 5. Charger system efficiency calibration diagram

The efficiency calibration principle of the charging system is shown in Figure 5. First, the sub-micrometer aerosol generator (MSP7388L) is used to generate single particle size particles, the charged particles reach the charge equilibrium distribution after the MSP1090 neutralization source. Then the charged particles are removed by the first electrostatic precipitator (ESP), only the neutral particles into the charger. The ultra-fine agglomerated nuclear particle counter (TSI 3776) is used to measure neutral particles passing through the first stage ESP, neutral particles passing through the second ESP outlet, and particles passing through the charger. The flow is controlled by the air pump built into the ultra-fine condensed core particle counter, where the flow rate of the airflow is controlled at 0.3L / Min.
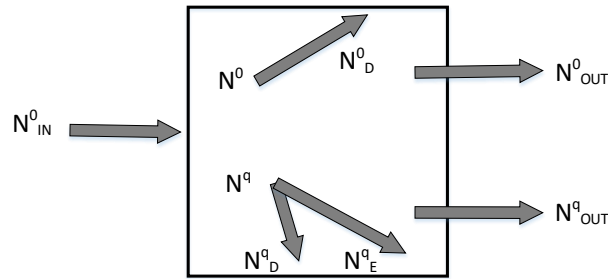
Figure 6. The schematic of the particle concentration change processes within the aerosol charger

The particle concentration change in the charger cavity is shown in figure 6, the monodisperse charged particles produced by Sub-Micrometer Aerosol Generator, a MSP1090 neutralizer and a ESP were used downstream of the Generator to obtain neutral test particles N_{IN}^0. After the charger is work, some particles will carry the charge N^q, some particles will continue to maintain neutral N^0, and some particles loss N_D^0 , N_D^q due to the diffusion movement. Some of the charged particles N_E^q are deflected to the walls of the charger cavity due to electrostatic forces. The exit particles of the charger have the remaining charged particles N_{OUT}^q and the non-charged particles N_{OUT}^0.

The intrinsic charge efficiency calibration diagram of the charger system is shown in Fig. 5. In this experiment the intrinsic charging efficiency was measured using the method of Romay and Pui[13], which was defined as:

$$\eta_{in} = 1 - \frac{N1}{N2}$$

Where N_1 is the number concentration of the particles measured downstream of the second electrostatic precipitator when charger system and electrostatic precipitator are working (the concentration of the neutral particles after the removal of the charged particles), N_2 is particle number concentration downstream of the secondary electrostatic precipitator when charger system and electrostatic precipitator are not working.

The extrinsic charging efficiency was evaluated by the method of Chen and Pui [14], is expressed as the ratio of the number of exit charged particles to the number of particles entering the charger, and described as

$$\eta_{ex} = \frac{N3 - N1/\text{pec}}{N4}$$

Where N_3 is the number concentration of particles exiting the charger, N_1 is the number concentration of neutral particles entering the charger, and pec is the transmittance of the neutral particles through the second electrostatic precipitator.

3. Experimental results and analysis

According preliminary measurement of the particle charge in different discharge corona current, the discharge corona current choose 1μA, 1.5μA, 3μA in negative corona discharge. In the test platform, the intrinsic and extrinsic charging efficiencies were calibrated from 50nm to 500nm each interval of 50nm particle size. The intrinsic charging efficiencies of charger system test results shown in figure 7.
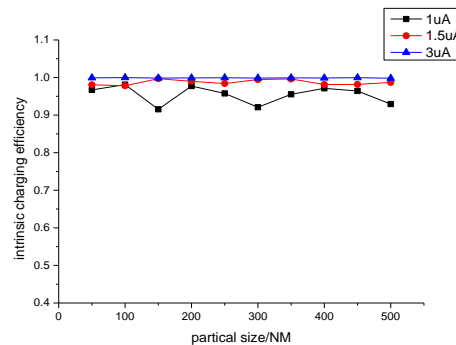
Figure 7. The intrinsic charging efficiency in different corona current

The results shown that the intrinsic charging efficiency with different particle size will increase with the increase of the discharge corona current. When the discharge corona current is 3µA, the intrinsic charge efficiency of the charger is more than 99%. It indicated that the charger of the export particles are mostly charged.
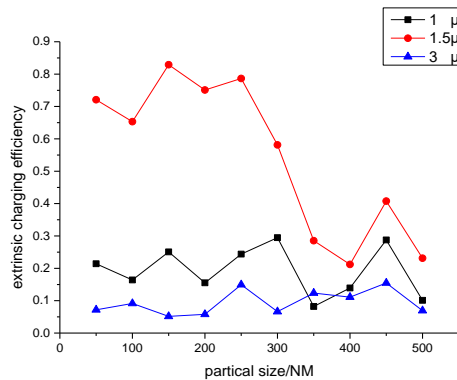

Figure 8. The extrinsic charging efficiency with different corona current

The extrinsic charging efficiency calibration results as shown in figure 8, experimental results shown that the extrinsic charging efficiency is best when corona current is 1.5µA, then 1µA, and the 3µA was worst. The extrinsic charging efficiency have a significant decline at 250nm when corona current is 1.5µA. The main reason is that the principle of charge for the use of corona discharge generated by the diffusion charging. Research has shown that the diffusion charging is the optimal way of charged particles when particle size is less than 200nm. In this paper, the charger design scheme is the diffusion charging. The experimental results the extrinsic charging efficiency decreased significantly in the particle size of 200nm current of 3µA, decreased significantly in the particle size of 250nm when discharge corona current at 1µA and 1.5µA also.

4. Conclusion:

A design of small unipolar aerosol charger with tip - arc discharge structure had been given, and a high voltage constant current discharge circuit had been designed in this paper. The intrinsic and extrinsic charging efficiencies of the charger system were calibrated. A corona current evaluation calibration system was proposed. The experimental result had indicated that negative corona discharge is better than the positive corona discharge in same corona current. It also shown that the bigger the corona discharge current is not the better. The intrinsic and extrinsic charging efficiencies of the charger system also had calibrated. The negative corona discharge is better than the positive corona discharge in same corona current from the result. The intrinsic charge efficiency of aerosol particles increases with the increase of corona current, which can as high as 99% when the negative discharge corona current is 3 µA. The extrinsic charging efficiency is required to optimize the analysis of the

specific experiment. In this paper the extrinsic charging efficiency had got the best performance when the corona current is 1.5μA with different particle size.

Acknowledgments

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