Design of intelligent sampler for large flow total suspended particulates

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Abstract. For the current nuclear radiation problem in society, it is very important to monitor the content of radionuclides in the atmosphere. The large flow total suspended particulate (TSP) sampler is the key equipment to monitor radionuclides. In this paper, a large flow total suspended particulate intelligent sampler is developed, which has high sampling accuracy, stable and reliable operation, and forms a complete set of automatic membrane changing particulates matter analyzer with analyzer and membrane sending mechanism, realizing 24-hour unattended automatic membrane changing sampling and analysis, and is used to collect suspended particulate matter in air in radiation monitoring stations and scientific research institutes at all levels to analyze the radionuclides: total α, β and γ and so on.

1. Introduction
At present, nearly 150 countries and regions in the world have carried out research, development and utilization of nuclear technology, and the annual output value of the world's nuclear technology application industry is nearly trillion US dollars[1-2]. With the development of nuclear technology application industry, nuclear safety issues such as nuclear leakage and radiation have become the focus of social attention. Many countries attach great importance to this problem, vigorously build radiation monitoring stations at all levels, and use large flow TSP sampler to measure the total α, β and γ and other radionuclides for sampling, analysis and monitoring [3-5]. The market urgently needs an unattended TSP automatic sampling and analysis system to realize intelligent environmental sampling and environmental monitoring [6].

Many scientific research institutions and enterprises in the field of environmental protection in the world are carrying out research in this field. Europe, the United States and other countries have developed atmospheric particulate matter sampling, analysis and monitoring equipment, such as EDM180 of Grimm company in Germany, Snow White of Senya company in Finland and Particles Plus 5301-AQM series in the United States [7-9]. These three samplers have the disadvantages of high price and no stable flow system. Most of the atmospheric particulate matter samplers made in China are single membrane samplers, which need manual on-site management and replacement of filter membrane; some research groups or enterprises in China have developed atmospheric particulate matter sampler, which uses frequency converter to control steady flow and can automatically replace filter membrane, but it is large and complex to operate, and lack of stable large flow automatic
membrane changing sampler. How to realize high-precision, stable and reliable remote automatic membrane change sampling is an application problem [10-11].

In this paper, aiming at the problem of monitoring radiation pollution sources, a large flow TSP intelligent sampler which can automatically replace the membrane, sample and control the ventilation flow is designed and developed to analyze the radionuclides of total α, β and γ in the atmosphere. The practical application test shows that the sampler can realize unattended and long-term stable automatic operation.

2. Design of intelligent sampler for large flow TSP

2.1. Overall structure design
The overall structure of the sampler is shown in figure 1. It is made of stainless steel and composite materials. When the atmosphere enters the sampler, suspended particles in the atmosphere will be attached to the filter membrane for sampling. The sampler is mainly composed of flow acquisition module, fan control module, gas automatic heating module, remote communication module and display module. Flow acquisition module: the orifice flow measurement principle is adopted to measure the differential pressure corresponding to different flows, and the flow is calculated through the differential pressure, which can realize high-efficiency, high-speed and high-precision flow acquisition. Fan control module: double fans are used for sampling, and the fan is closed-loop controlled through PID regulation. Automatic gas heating module: an independent controller is used to automatically adjust the heater for gas heating. Remote communication module: complete the functions of automatic replacement of filter membrane and unattended sampling through remote control of the platform. Display module: display the equipment operation status information, and realize the functions of sampling setting, system setting, data query and log through friendly man-machine interface.

2.2. Design of automatic membrane replacement mechanism
The way to replace the filter membrane of the sampler is to transfer the filter membrane laterally. As shown in figure 2, the automatic membrane replacement is realized by remotely controlling the membrane lifting device of the sampler and combined with the filter membrane transmission mechanism. After receiving the remote membrane replacement command, the sampler lifts the filter membrane pressed frame, and the two reduction motors rotate in reverse. Using the cam structure, as
shown in figure 3, raise the filter membrane pressed frame until the stop of the pressed frame touches the travel switch of the upper limit position. Then transfer the filter membrane horizontally and replace the old and new filter membranes. After completion, the pressed frame is lowered, and the two reduction motors are reversed to press the filter membrane pressed frame under the cam structure until the stop touches the travel switch at the lower limit to complete the automatic membrane replacement action. If the membrane lifting (pressing) action is not completed after timeout, the system will set the automatic alarm function and close the reduction motor in time.

Figure 2. Physical drawing of membrane replacement structure          Figure 3. Cam structure

2.3. Hardware design
The hardware composition of the sampler is shown in figure 4, mainly including main controller, fan, communication platform, LCD display, power supply and lifting and pressing membrane. The lifting and pressing membrane part includes a reduction motor and upper and lower limit sensors. In order to ensure the stability of signal transmission, the integrated circuit design is adopted, and the power supply and signal are electrically isolated. Cortex-M3 is selected as the main controller, and the kernel architecture is shown in figure 5.

Figure 4. Main hardware components
2.4. Sampling process design

The system includes two modes: timing sampling and quantitative sampling. The sampling mode and corresponding parameters can be set in advance during standby and the workflow is shown in figure 6.

2.5. Design of constant flow control scheme

The flow stability and accuracy of sampler are important factors affecting sampling accuracy. In order to achieve accurate flow control, a constant flow control method of sampler based on dual pump flow acquisition and calculation compensation is proposed.

The dual pump flow acquisition mode is adopted for sampling, so as to ensure high-efficiency large flow acquisition. The sampling system is composed of control system and flow control unit. The control system adopts high-speed ARM processing chip with Cortex-M3 architecture. The flow control unit is composed of flow control board, proportional valve and flow sensor. The sampling flow is preset and accurately controlled through the control system and flow control unit, so as to ensure the
stability of flow in the sampling process. Specific implementation method: the orifice flowmeter is used to transmit the differential pressure signal of the gas proportional to the flow to the high-precision micro pressure sensor, and the sensor converts the flow digital signal to the microprocessor. The microprocessor processes and analyzes the digital signal and calculates the actual flow. The actual flow is used as the feedback signal to intelligently adjust the speed of the motor, so as to indirectly adjust the flow, stabilize the flow and realize the closed-loop regulation and control of the flow.

In the sampling process, the resistance of the sampling membrane will increase with the advance of the sampling time, resulting in the decrease of the sampling flow. In order to ensure the constant sampling flow, a flow degradation protection control method is designed. When the current flow is lower than the flow target value due to excessive filter membrane resistance, the instrument automatically reduces the target flow and appropriately prolongs the sampling time. The degradation times and protection threshold can be preset according to specific requirements, and the degradation times can be set as 1 ~ 5. If the current flow is lower than the lower limit of protection flow and lasts for 1 minute, the instrument stops sampling. The flow degradation protection control flow is shown in figure 7.

![Flow degradation protection control process](image)

Figure 7. Flow degradation protection control process

3. System test
The intelligent sampler for large flow TSP matter is tested according to the China's national environmental protection standard “technical requirements and test procedures for total suspended particulates sampler (HJ/T374-2007)” [12].

The test results show that the sampler meets the requirements of China's national environmental protection standard “large flow total suspended particulate matter sampler (HJ/T374-2007)”; the sampler has the advantages of convenient operation, high sampling accuracy, stable and reliable structural performance, and has the functions of power-off memory, serial port self-start, system fault diagnosis, instantaneous flow curve display, historical data query and so on; it has timing sampling and quantitative sampling mode, which is suitable for different sampling requirements; it has high-
precision, stable and reliable remote automatic membrane replacement sampling function, and can realize 24-hour unattended automatic membrane replacement sampling. The main performance indexes are shown in table 1.

| Test items                  | Performance index                  |
|-----------------------------|------------------------------------|
| Maximum sampling time       | 99 hours59 minutes                 |
| Time control range          | 1 minute-99 hours 59 minutes       |
| Aerosol flow range          | (1.5~4.0)m³/min                    |
| Aerosol flow accuracy       | ≤5%                                |
| Aerosol flow stability      | ≤±5%                               |
| Timing accuracy             | 24h ±2s                            |
| Temperature range           | -20～60℃                           |
| Temperature accuracy        | ±1℃                                |
| Atmospheric pressure range  | 80～120 kPa                         |
| Atmospheric pressure accuracy| ±0.5%                             |
| Noise                       | ≤60dB                              |

4. Conclusion
For the current nuclear radiation problem in society, it is very important to monitor radionuclides in the atmosphere. The large flow total suspended particulates sampler is the key equipment to monitor radionuclides. In this paper, a large flow total suspended particulates intelligent sampler is designed and developed, which realizes automatic membrane replacement through membrane transmission mechanism and membrane lifting and pressing device, and realizes fan closed-loop control through PID regulation; the constant flow control is realized through dual pump flow acquisition, calculation compensation and flow degradation protection.

The test result shows that the sampler has the functions of timing sampling and quantitative sampling, convenient operation and high sampling accuracy. It can realize unattended automatic membrane replacement sampling and long-term stable operation. A complete set of automatic membrane replacement particle analyzer is formed with the analyzer and membrane transmission mechanism, which is used by radiation monitoring stations at all levels and scientific research institutes to collect suspended particles in the air to analyze radionuclides: total α, β and γ and so on.

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