A standard sample determination method for the testing of smoke detectors and its application research

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Abstract. The stability of the standard sample plays a key role in the testing of the smoke detectors. A scientific and effective standard sample selection scheme is proposed in this paper. The repeatability and uniformity of the tested samples are evaluated before and after the environmental acceleration testing, and the most stable standard sample is obtained. At the same time, this paper explores the new application of the standard sample, which can be used in the calibration of the measuring ionization chamber (MIC). This work can greatly reduce the selection time and provide the standard samples for the laboratory of the smoke detectors testing which is scientific and reliable. At the same time, the difficult problem of the calibration of the measuring ionization chamber (MIC) is solved here.

1 Introductions

The standard sample plays an important role in the testing of the smoke detectors. It can determine the conformity and stability of the overall test environment and equipment. Also, it can debug and modify the important test equipment (such as the smoke tunnel). If there is no stable and reliable standard sample in the test, it will easily cause errors in the test and affect the test accuracy.

A scientific and effective standard sample selection scheme is proposed in this paper. The repeatability and uniformity of the tested samples before and after the environmental acceleration test are evaluated, and the most stable sample is obtained. This scheme can greatly reduce the sampling period. The evaluation method is scientific and reliable, which can provide standard samples for the scientific testing of the smoke detectors.

At the same time, a new application of the standard sample is proposed. The sample can be used in the calibration of the measuring ionization chamber (MIC) [1] in the testing of smoke detectors. When the measuring ionization chamber (MIC) [2-4] is used in smoke tunnel test and fire sensitivity test, the measurement accuracy is very important, because it affects the measurement accuracy of the whole measurement system. However, the calibration of the measuring ionization chamber (MIC) is expensive and complicated because of the radiation source inside the device. This paper presents a simple procedure for determining the relative accuracy of the measuring ionization chamber (MIC), which can be popularized to relevant laboratories and product manufacturers.

2 Determination of the standard sample

The standard sample should be stable in time and space, so we designed a set of experimental procedures to determine the standard sample. Select a group of smoke detectors with different levels. Carry out repeatability test and directional dependence test according to the standard procedure. After the completion of the test, the environmental acceleration test was applied to simulate the influence of the environmental factors that might be encountered in storage or transportation. Then the repeatability test and directional dependence test were carried out again. The sample with the best performance parameters and the best time and space stability can be used as the standard sample. The flow chart of standard sample selection is as follows:

Fig. 1. The flow chart of standard sample selection.

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The following is the standard sample selection for 5 smoke detectors that have been rough-selected. Testing environment: Air temperature is 20.6°C and air humidity is 45.4%. Air velocity is 0.2m/s. Condition: The rate of increase of aerosol density is 0.05min⁻¹. The flow rate of aerosol is 20 l min⁻¹. The flow rate of vacuum pump is 30 l min⁻¹. Test equipment: measuring ionization chamber (MIC) : Delta MIC EC-912, smoke tunnel: AWT 2800.

The test sample N was marked as 1#-5# respectively. Repeatability test and directional dependence test were carried out before and after the environmental acceleration test. The temporal and spatial stability of the samples have been investigated. In order to eliminate the influence of spatial heterogeneity in the smoke tunnel, the placement of sample N and measuring ionization chamber (MIC) was perpendicular to the smoke flow direction. The sample placement position is shown in Figure 2:

Fig. 2. Schematic diagram of the position of the samples.

Conduct repeatability and directional dependence tests on 1#-5# samples. The repeatability test detects the consistency of the response threshold value to show that the detector has stable behaviour with respect to its sensitivity even after a number of alarm. The response threshold value of the detector using ionization is the y value of smoke concentration when the detector sends fire alarm signal. Six response thresholds value were measured at any azimuth of the normal working position of the sample. The maximum and minimum values of the six response thresholds were y_{max} and y_{min} , respectively. The ratio of response threshold values was $y_{max} : y_{min}$ to evaluate the repeatability of the sample. The smaller the ratio, the better the sample repeatability. The test data of repeatability test before the environmental test of each sample is shown in Table 1:

Table 1. Repeatability test data of the samples before the environmental test.

Sample No. Times	1#	2#	3#	4#	5#
1	1.17	0.97	1.18	1.07	1.20
2	1.15	0.97	1.18	1.03	1.00
3	1.16	1.01	1.17	1.05	1.10
4	1.16	1.01	1.16	1.05	1.10
5	1.18	0.99	1.18	1.07	1.10
6	1.14	0.99	1.18	1.03	1.10
$y_{max} : y_{min}$	1.04	1.04	1.02	1.04	1.20

It can be seen from the above table that sample No.3 has the best repeatability and sample No.5 has the worst repeatability.

In order to find the sample with the closest performance in different directions, directional dependence test can detect the smoke intake performance of the sample in different directions, so as to meet the requirement of spatial uniformity of the standard sample. Take the indicator light position of the sample under test as 0° and test its response threshold value according to standard requirements. After each measurement, the sample was rotated 45 degrees around its vertical axis in the same direction for 8 times. See Figure 3 for the bearing marker of the sample:

Fig. 3. Schematic diagram of sample bearing indication.

The orientation corresponding to the maximum response threshold value y_{max} and the minimum response threshold value y_{min} of the sample was recorded. The ratio of the sample response threshold value $y_{max} : y_{min}$ was used to evaluate the uniformity of the space. The smaller the ratio, the difference is smaller of the response threshold value in all directions. The better the orientation of the sample, the more suitable for the standard sample. The test data of each sample before the environmental test are shown in Table 2 and Figure 4:

Table 2. Directional dependence test data of the samples before the environmental test.

Angle(degree) Sample No.	0	45	90	135
1#	1.18	1.18	1.18	1.18
2#	1.03	1.03	1.03	1.03
3#	1.14	1.14	1.14	1.14
4#	1.07	1.10	1.10	1.07
5#	1.14	1.14	1.10	1.10
Angle(degree) Sample No.	180	225	270	315
1#	1.18	1.14	1.14	1.14
2#	1.03	0.99	1.03	0.99
3#	1.14	1.11	1.11	1.11
4#	1.10	1.10	1.07	1.07
5#	1.10	1.10	1.10	1.10

Fig. 4. Directional dependence test data of the samples before the environmental test.

Table 3 shows the calculation results of each sample of directional dependence test. It can be seen from Table 3 that No. 3 and No. 4 samples have good spatial uniformity performance.

Table 3. Directional dependence test result before the environmental test.

Sample No. Ratio	1#	2#	3#	4#	5#
$y_{max} : y_{min}$	1.04	1.04	1.03	1.03	1.04

Environmental test implementation: Accelerated environmental test was carried out on 5 samples to be tested, mainly simulating the environmental conditions that the samples might encounter in storage and transportation. The details are as follows: Vibration test: frequency: 10-55Hz; amplitude: 0.75mm; test duration: 6 hours. Climate change test: temperature 40°C, humidity 95%, test duration 48 hours.

After the environmental test, repeatability test and directional dependence test were carried out on the samples. The repeatability test results of the samples were shown in Table 4, indicating that No. 3 sample had the best repeatability and the best time stability after the environmental test.

Table 4. Repeatability test data of the samples after the environmental test.

Sample No. Times	1#	2#	3#	4#	5#
1	1.2	1.03	1.16	1.07	1.16
2	1.16	1.03	1.16	1.03	1.16
3	1.18	1.05	1.15	1.05	1.16
4	1.18	1.01	1.17	1.05	1.16
5	1.18	1.03	1.16	1.07	1.14
6	1.18	1.03	1.16	1.07	1.18
$y_{max} : y_{min}$	1.04	1.04	1.02	1.04	1.04

The directional dependence test data of each sample after the environmental test are shown in Table 5 and Figure 5:

Table 5. Directional dependence test data of the samples after the environmental test.

Angle(degree) Sample No.	0	45	90	135
1#	1.18	1.17	1.18	1.17
2#	1.03	1.04	1.03	1.05
3#	1.14	1.14	1.14	1.14
4#	1.07	1.10	1.12	1.08
5#	1.14	1.13	1.10	1.10
Angle(degree) Sample No.	180	225	270	315
1#	1.18	1.15	1.14	1.15
2#	1.03	0.99	1.03	0.99
3#	1.14	1.12	1.11	1.11
4#	1.10	1.10	1.07	1.07
5#	1.10	1.10	1.10	1.10

Fig. 5. Directional dependence test data of the samples after the environmental test.

Table 6 shows the calculation results of each sample of directional dependence test after the environmental test.

Table 6. Directional dependence test result after the environmental test.

Sample No. Ratio	1#	2#	3#	4#	5#
$y_{max} : y_{min}$	1.04	1.06	1.03	1.05	1.04

By analyzing the directional dependence test data of 5 samples to be selected, it can be seen that No.3 sample has the best spatial stability and the best results of test data.

Based on the test data of 5 samples before and after the environmental test, it can be concluded that No.3 sample has the best stability in time and space, so No.3 sample can be selected as the standard sample.

3 New applications of the standard samples

It is known that the standard sample can be used for basic debugging and modification of basic environment such as smoke tunnel due to its stable performance. Here we propose a new application scheme which can be used in the calibration of the measuring ionization chamber (MIC).

The measuring ionization chamber (MIC). is a key equipment to measure the smoke concentration continuously by ionization method. It is the key equipment which is used in the smoke tunnel measurements and fire sensitivity tests. The measurement accuracy of the measuring ionization chamber (MIC) is the benchmark to evaluate the response threshold value and fire sensitivity of the smoke detectors. The inaccuracy of the performance index of the measuring ionization chamber (MIC) will lead to the failure to accurately determine the response threshold value and sensitivity of the smoke detectors under test, and thus failing to accurately and effectively distinguish the false alarm or delayed alarm phenomenon of the smoke detectors, thus causing serious safety accidents.

The response threshold of the smoke detectors using ionization is characterized by a non-dimensional quantity y or X which are derived from the relative change of the current flowing in a measuring ionization chamber, and which are related to the particle concentration of the test aerosol, measured in the proximity of the detector, at the moment that it generates an alarm signal.

According to BS EN54-7:2008 "Fire detection and fire alarm systems Part 7: Smoke detectors -Point smoke detectors that operate using scattered light, transmitted light or ionization" and other relative standard [5-10], MIC consists of a measuring chamber, an electronic amplifier and a method of continuously sucking in a sample of the aerosol or smoke to be measured.

The measuring chamber contains a measuring volume a suitable means by which the sampled air is sucked in and passes the measuring volume in such a way that the aerosol/smoke particles diffuse into the volume. This diffusion is such that the flow of ions within the measuring volume is not disturbed by air movements. The air within the measuring volume is ionized by alpha radiation from an americium radioactive source, such that there is bipolar flow of ions when an electrical voltage is applied between the electrodes. This flow of ions is affected by the aerosol or smoke particles in a known manner. The relative variation in the current of ions is used as a measurement of the aerosol or smoke concentration.

The measured smoke densities is expressed in terms of the dimensionless quantity defined by the equation:

$$X = \frac{I_0 - I}{I_0}, \quad 0 \leq X \leq 1 \quad (1)$$

Where I_0 is the quiescent ionization chamber current in clean air and I is the ionization chamber current in presence of smoke.

The determination of the accuracy of the measuring ionization chamber (MIC) has always been the focus of the users of the measuring ionization chamber (MIC), such as testing laboratory, system manufactory, industry authority department and research institutions. However, there are few research on this problem, which are basically blank, resulting in the absence of relevant determination methods, which cannot effectively evaluate the reliability and accuracy of the measuring ionization chamber (MIC), thus bringing some safety

risks. Wang Tingting et al. once proposed a method to determine its accuracy by using laboratory comparison and assess its test uncertainty [11-12]. Here, we proposed a standard sample method to determine the accuracy of the measuring ionization chamber (MIC).

The measuring ionization chamber (MIC) to be evaluated and the stable standard sample are placed in the same smoke tunnel. On the premise of ensuring the uniformity and stability of the smoke tunnel and the stability of the standard sample, the relative accuracy of the measuring ionization chamber (MIC) to be evaluated was determined by comparing it's testing value with the response threshold value of the standard sample. According to section 4.1.4 of GB 4715-2005, the tolerance of all test data is $\pm 5\%$. We believe that if the data difference between the measuring ionization chamber (MIC) to be evaluated and the standard sample is less than 5%, the measuring ionization chamber (MIC) is reliable.

4 Conclusion

A scientific and effective standard sample selection scheme is proposed in this paper. The repeatability and uniformity of the tested samples before and after the environmental acceleration test are evaluated, and the most stable sample is obtained. At the same time, a new application of the standard sample is proposed. The sample can be used in the calibration of the measuring ionization chamber (MIC). A simple procedure to determine the relative accuracy of the measuring ionization chamber (MIC) is proposed, which can be popularized to relevant laboratories and product manufacturers.

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