On Quality Evaluation and Analysis of Metrological Verification and Detection

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Abstract: With the rapid development of China’s economy and society, under the existing economic system, measurement work is of great significance to promote market development and improve people’s living standards. The quality evaluation of testing work is an important means to ensure the accuracy of measurement. Based on the analysis of several factors affecting the quality of measurement work, this paper takes the ionizing radiation monitoring quality as an example, and makes a concrete exposition on the evaluation and analysis of the quality of metrological verification work.

Key words: Metrological verification, test the quality of work, measuring instruments, ionization chamber.

1. Background Introduction

Measurement refers to the activities of realizing unified units and accurate and reliable values. In industry, measurement accuracy is the primary quality factor of the service provided by manufactured products. Taking the ionization chamber as an example, in the measurement of ionizing radiation, when the silicon wafer in the front section of the detector collides with ionized particles, it is easy to cause lattice damage and increase the band gap width, which greatly reduces the capture rate of charged particles and makes the instrument reading low. Therefore, metrological verification is needed to evaluate the metrological performance of measuring instruments. The main methods to realize accurate value include value transmission and value traceability. Quantity value transfer transmits the unit value of measurement reproduced by the national measurement standard to the work measuring instruments through the measurement standards of each grade, and the traceability of quantity value makes the measurement results consistent with the national measurement standard through a continuous comparison chain [1].

Traceability includes verification and calibration, and both verification and calibration need to evaluate the quality of detection work.

2. Overview of Quality Evaluation of Metrology and Testing Work

Metrology and measurement work is a basic technical work, which is used to serve many fields such as social economy, science and culture, so metrology work has two characteristics: technology and service. The quality of measurement work is the degree to which the inherent characteristics of measurement inspection activities meet customer requirements. The core of metrological verification and testing is whether the quality of metrological work meets the standards. It includes two factors: verification result and verification process, which complement each other [2]. A good verification process quality is the cornerstone to ensure the quality of the whole measurement work, and the quality of each process link can finally be reflected in the result quality of measurement work.

3. Taking Ionization Chamber as An Example

This paper analyzes the factors affecting the quality of measurement and testing. The factors affecting the
quality of measurement and testing mainly come from equipment, environment, materials, etc. These factors have an impact on the quality of testing results at the same time in the testing process, which is also the manufacturing process of testing quality.

3.1 Analysis of Quality Inspection Results by Equipment

The configuration and management of measuring equipment includes the management of measuring equipment, the legal management of measuring standards, the technical requirements of testing equipment (including software) and the mark management of equipment verification status [3]. The management of measuring equipment includes the requirements of safe disposal, transportation, storage, use and maintenance of equipment. The measurement organization can ensure the normal operation of the equipment effectively and prevent the degradation of the performance of the equipment caused by contamination by establishing a set of equipment management procedures [4]. For unqualified verification equipment, such as obvious error results, analysis of quality inspection results by Guide 2.1 equipment due to improper operation, configuration and management of measurement equipment include management of measurement equipment, legal management of measurement standards, technical requirements of testing equipment (including software) and mark management of equipment verification status, etc. [5]. The management of measuring equipment includes the requirements of safe disposal, transportation, storage, use and maintenance of equipment. The measurement organization can ensure the normal operation of the equipment effectively and prevent the degradation of the performance of the equipment caused by contamination by establishing a set of equipment management procedures. For unqualified verification equipment, such as obvious error results and exceeding the use limit due to improper operation, the equipment shall be stopped in time and labeled until the repair is qualified or the calibration shows that it can work normally. As we all know, the ionization chamber measures ionizing radiation mainly through electron pair effect, which converts the energy captured by the detector into the number of electrons, thus calculating the amount of ionizing radiation. In actual detector devices, the energy deposition of secondary electrons, that is, the measuring point of absorbed energy, is not at the same position as the acting point of total kinetic energy released by photons to secondary electrons. Only assume that the energy carried away by secondary electrons per unit volume $V$ is exactly equal to the energy of secondary electrons entering the volume, that is, the problem of small deviation of action point can be ignored. The influence of measuring points of measuring equipment on the quality of detection is not considered in the existing General Regulations on Quality Assurance of Ionizing Radiation Monitoring. In fact, due to the difference of ionization chamber shape, incident window, material and detection ray quality, it is necessary to redefine the effective measurement point of the equipment when detecting ionizing radiation [6].

As shown in Fig. 1, the effective measurement point $P_{\text{eff}}$ is located in front of the central point $P$ of the ionization chamber (facing the incident direction of ionizing radiation), and $r$ represents the radius of the ionization chamber. Monte Carlo simulates rays with different energies, and $P_{\text{eff}}$ is $0.5r$ for high-energy electron beams; For high energy X-rays, $P_{\text{eff}}$ is $0.6r$;

![Fig. 1 Schematic diagram of effective measuring points in ionization chamber.](image-url)
\( P_{\text{eff}} \) and geometrical center coincide with the median energy X-ray. In order to ensure the measurement accuracy of the ionization chamber, besides sending the ionization chamber and electrometer to the national standard laboratory for calibration regularly (generally once a year), it is necessary to know the characteristics of the ionization chamber equipment itself in actual use.

3.1.1 Directivity of Ionization Chamber

Due to the structural characteristics of the ionization chamber, the charged ions entering the collector are different after the ray incidents from different directions are refracted and reflected. Therefore, when using the ionization chamber, the probe plane should be kept perpendicular to the ray incident angle, for example, when using the finger ionization chamber, the central axis of the ionization chamber body should be kept perpendicular to the ray incident angle.

Fig. 2 shows the relationship between the sensitivity of finger ionization chamber and the incident angle of ray beam. It can be clearly seen from the figure that no matter what kind of ray, the deviation of ray incident angle greatly affects the measurement of ray intensity, and this error has a great influence on the quality evaluation of metrological verification in ionization chamber.

3.1.2 Saturation and Recombination Characteristics of Ionization Chamber

The secondary ions produced by the primary charged particles in the gas cavity will diffuse from the electron-enriched region to the electron-sparse region according to the overall charged particle concentration without the influence of external force, which leads to the macroscopic charged particle flow, which is called the diffusion movement of ions and electrons. In the process of electron diffusion, electrons with different polarities will eliminate their electrical properties due to charge attraction, which is called recombination effect.

Fig. 3 shows the saturation characteristic graph of ionization chamber. Only in the AB section, the ionization chamber is in the normal working area, so in the measurement and inspection work, it is necessary to ensure that the ionization chamber works in the saturation area to avoid large measurement errors in the ionization chamber. In addition, even if the ionization chamber works in the saturation region, the measurement results will be affected due to the compound effect of positive and negative ions. The author suggests that different voltage values should be used to measure the intensity of ionizing radiation and fit the curve in the metrological verification of ionization chamber, so as to reduce the error caused by compound effect.

Fig. 2  Relationship curve between sensitivity of finger ionization chamber and incident angle of ray beam.

Fig. 3 saturation characteristic curve of ionization chamber.
3.1.3 Rod Effect of Ionization Chamber

The sensitivity of the ionization chamber is also affected by the irradiation range of the metal rod and cable in the ionizing radiation field. Because the weak current produced by metal rod, insulator and cable in radiation field is superimposed on the signal current of ionization chamber, the leakage of ionization chamber rod is formed, which is called rod effect. Therefore, in the actual metrological calibration, the irradiated length of the detector should be kept unchanged.

3.2 Environmental Analysis of Quality Inspection Results

Environment refers to the temperature, humidity, mechanical environment and electromagnetic interference of the experimental site. Different verification environments need to be supervised according to the provisions of different guidance documents. Because of the diffusivity of environmental factors, the mutual influence of environmental factors is often caused in the verification process, which leads to the error value that cannot be eliminated in the verification results. Staff should strictly control the verification area according to the corresponding process specifications, and try to avoid the occurrence of similar problems. When measuring the ionizing radiation value in the environment of non-closed ionization chamber, the air quality in the cavity of ionization chamber changes with the change of temperature and air pressure in the big environment, that is, the increase of air pressure or the decrease of temperature will lead to the increase of air quality, which will affect the measurement sensitivity of ionization chamber. Therefore, when the ionization chamber is used in the field, it is necessary to carry out environmental correction for the instrument, and the relationship between the correction coefficient and temperature and air pressure is shown in Eq. (1).

\[ K_p = \frac{273 + t}{273 + T} \times \frac{1013}{p} \]  

(1)

In the formula \( T \) is the temperature of the ionization chamber measured in the national standard laboratory, generally 20 °C or 22 °C, \( T \) is the temperature measured in the field, and \( P \) is the atmospheric pressure measured in the field. It can be clearly seen from Eq. (1) that every 3 °C change in temperature has a 1% influence on the accuracy error of the measured value in the ionization chamber. Therefore, it is necessary to grasp the accurate field temperature and air pressure, introduce the environmental error factor into the verification link in time, and correct the appraisal results when measuring and verifying the ionization chamber.

3.3 Analysis of Quality Test Results by Test Samples

In the process of metrological verification, whether the samples are representative, effective and complete will determine whether the whole metrological verification is meaningful or not. Therefore, strict quality control must be carried out in the process of accepting sample materials. The intermediate links of verification and calibration samples include transportation, acceptance, disposal, protection, storage, retention and cleaning. Standardized treatment of sample management can not only effectively protect the integrity of samples and maintain the self-interests of testing institutions and clients, but also lay a good foundation for the follow-up verification work. There are four basic requirements for sample disposal. First, it is required to establish program documents related to customer sample disposal; Second, it is required to establish an identification system for customer samples; Third, it is required to make records and inspections when accepting customer samples; And fourth, it is required to establish a protection mechanism to prevent customer samples from being damaged. As far as ionization chamber is concerned, when determining the absorbed dose, different calculation parameters of ionization rays are more or less different, so it is necessary to make clear the difference of measured ionization radiation quality.
and choose different calculation formulas for detection. In addition, the recommended quality standards for measuring ionization chambers with different energies and rays are also different.

### 3.4 Quantity Traceability Analysis of Quality Inspection Results

Traceability of quantity refers to linking the measurement results and the quantity of measurement standards with the national benchmark through a continuous comparison chain to determine the uncertainty. In order to ensure the fluency and accuracy of value traceability, the testing institution should carry out verification work in strict accordance with the corresponding provisions and specifications. In case of any situation outside or not applicable to the specifications, the measuring institution should formulate corresponding special and legal procedures to ensure the accuracy of work quality [7]. The highest measurement standard of the institution belongs to the compulsory verification of measuring instruments, and its value traceability should be traced back to the legal metrological verification institution formulated by the government department; The value of reference materials should be traced back to the international system of units or the reference materials certified by the state. For some key measurement standards, such as reference materials whose measurement results have important economic value and safety function, in order to ensure the accuracy and reliability of the measurement values, the program plan should be checked regularly within the interval between two verification and calibration. The theoretical formula for measuring absorbed dose in ionization chamber is only applicable to ideal ionization chamber, including assuming that the wall material of ionization chamber is equivalent to air, the cavity volume can be accurately measured and the electron balance in the cavity can be achieved. In order to meet these conditions, the design and fabrication process of ionization chamber are required to be quite high.

Therefore, in the field dose measurement, many conditions are often approximated, and the approximate coefficients are selected and determined. This work must be carried out by the national metrological supervision department as the first-class standard laboratory or the local metrological supervision department authorized by it and transmitted by the metrological standards as the second-class standard laboratory. According to the absorbed dose measurement standard, the national first-class standard laboratory, Beijing Chinese Academy of Metrology has established a national first-class standard, and established a secondary standard laboratory in qualified provinces and cities, which is responsible for calibrating and verifying the measuring instruments used in the field, and gives the relevant exposure calibration factor \( N_e \) and air specific potential kinetic energy calibration factor \( N_k \). Combining the calibration factors \( K_m \) and \( K_{att} \), the calibration factor \( ND \) of the ionization chamber to be measured by the user is finally obtained from Eq. (2).

\[
ND = N_k(1-g)K_mK_{att}
\]  

### 4. Measures to Improve the Quality of Metrological Verification

#### 4.1 Strengthen the Publicity of Metrological Verification

From the current situation, China’s metrological verification work is gradually improving, which will not only affect the development of the metrological industry, but also have a close relationship with the development of related industries. Therefore, in order to make the metrological verification work get more attention, it is necessary to strengthen the publicity of metrological verification work, especially in the publicity of relevant laws and regulations. Only through the vigorous publicity of metrological verification can people better understand the metrological verification work, make people really benefit from metrological
verification work, and promote the better development of metrological verification work.

4.2 Strengthen the Maintenance of Measuring Instruments and Improve the Verification Process

Measuring instruments need to be used in the measurement verification work, so the instrument maintenance needs to be carried out in accordance with the regulations, so as to better play the role of the instrument and avoid problems in the use of the instrument. At the same time, it is necessary to conduct scientific inspection and maintenance of measuring instruments on a regular basis. In terms of metrological verification process, it is necessary to strictly abide by the technical requirements to better optimize all links, and finally complete the metrological verification work in an orderly manner. At present, due to the imperfection of the verification process, the verification quality is affected to a certain extent, and there are many such problems. We need to formulate a unified verification process in combination with our own situation, so as to fundamentally promote the better development of metrological verification.

4.3 Improve Measurement Rules and Regulations and Select Scientific Verification Methods

The rapid development of modern science and technology provides richer technical means for metrological verification, which makes the quality control task of metrological verification difficult to complete under the traditional mode more feasible. Therefore, it is necessary to establish and improve a perfect, hierarchical and differentiated management system of measurement verification in combination with the latest development trend and work objectives of measurement verification, so as to provide institutional guarantee and basis for the formation of specific working methods and measures of measurement verification, and fully highlight the advantages and value of measurement verification system. At the same time, we should comprehensively select scientific and reasonable verification methods, select the most applicable, efficient and appropriate verification methods for different objects and combine with their actual needs of metrological verification, and clarify the specific operation methods and application steps of verification technology, so as to build a perfect verification method system and use effective verification methods to promote the effective development of metrological verification.

5. Summary

Constantly improving the management of metrological verification has irreplaceable practical significance for promoting the improvement of the quality of metrological verification management and the development of social and economic level in China. Relevant people should start from different levels, from the formulation of laws and regulations of the national government to the talent reserve of instrument manufacturing enterprises, which are the help that China needs to become a world metrology power. On this basis, the relevant staff should pay more attention to the management of metrological verification, and ensure that all aspects of management can be strictly implemented in accordance with relevant standards, so as to provide help for promoting the reform process of metrological verification management in China.

References

