Study on the performance of X-ray machines used in K-fluorescent devices

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Abstract: Since Roentgen discovered X-rays, X-rays have been widely used in medical diagnosis and industrial non-destructive testing. With the improvement of the performance of aviation technology and instrumentation, higher requirements have been set for the calibration of detectors. X-ray machine performance is very important for calibration. Tube voltage, tube current, and inherent filtration are important parameters of the X-ray machine and directly affect the image imaging quality and radiation dose. Here, the voltage performance of the X-ray machine was measured using HPGe detector. Measure the tube voltage of the X-ray machine using the end of the spectrum method, it is shown that the performance of the X-ray machine shows the tube voltage within ±2%. Measurement of the linearity of the X-ray tube current and current stability using the PTW30013 ionisation chamber. The relative deviation of the actual measured tube current is 0.08%. The inherent filtration of the X-ray machine was measured by the half-value layer method, and the inherent filtration was 0.058 mm Al. The inherent filtration of the K-fluorescent device was measured to be 1.487 mm Al.

1 Introduction
The energy linearity, energy resolution, detection efficiency, and energy response matrix of X-ray detectors are very important [1–5]. There are usually four ways to calibrate a detector: radioactive isotopes, k-fluorescence, X-ray machines (relying on monochromators), and synchrotron radiation devices [6]. K-fluorescence device has the advantages of large photon fluence, multiple energy points, and low price [7, 8]. For accurate calibration, when using k-fluorescence calibration detectors, the performance of the X-ray machine needs to be known. The tube voltage, tube current, and inherent filtering of the X-ray machine are important parameters for the quality control of the X-ray machine and directly affects the image imaging quality and radiation dose size. X-ray machine performance can be obtained from the manufacturer's instructions, but the actual application of X-ray machine tube voltage, tube current is not consistent with the instructions. The measurement of X-ray tube voltage at home and abroad is usually done using a voltmeter. However, the internal circuit of the X-ray machine is complicated. This method cannot accurately obtain the voltage of the X-ray machine during operation. Here, the end-point energy spectrum method is used to measure the voltage of the X-ray machine. It is only necessary to use the HPGe detector to measure the energy spectrum to obtain the voltage of the X-ray machine. The inherent filtration of X-ray machines and k-fluorescent devices was measured according to the method recommended by ISO 4037.

2 Tube current measurement
The stability of the X-ray tube current is an important parameter for the stability of the X-ray machine. This experiment uses PTW30013 ionisation chamber and UNIDOS to measure the linear relationship between X-ray machine radiation dose and X-ray tube current, verify the accuracy of the X-ray tube current, repeat the X-ray tube current measurement, verify its stability (Fig. 1).

2.1 Tube current linear measurement
The ionisation chamber has a high voltage of 400 kV. The PTW30013 ionisation chamber is fixed at 120 cm in front of the X-ray machine. The X-ray tube voltage is 100 kV. Measure 0.5–5 mA separately, measure one group every 0.5 mA, and fit the measurement result. The measurement result is shown in Fig. 2.

From the fitting results, it can be seen that the ionisation charge is linearly related to the tube current.
2.2 Tube current repeatability measurement

In order to verify the stability of the tube current, it is necessary to repeat the measurement of the tube current, the PTW30013 ionisation chamber is fixed in the X-ray machine 120 cm, the ionisation chamber high voltage is 400 kv, the opto-mechanical tube voltage is 100 kv, the tube current is 0.5 mA, the measurement ten group. The results are shown in Table 1.

The relative deviation of the actual measured tube current is 0.08%.

According to data analysis, the tube current stability of the X-ray machine is excellent (Table 2).

3. Tube voltage stability measurement

The tube voltage of the X-ray machine is an important parameter for the quality control of the X-ray machine. It is an important parameter for measuring the X-ray national reference and the standard device reference radiation quality [9]. This experiment mainly uses the energy spectrum end point method of the high-purity germanium detector to select seven energy points to measure the tube voltage of the X-ray optics. The radiation generated by the X-ray machine is bremsstrahlung [10]. The maximum energy generated by the photon is determined by the tube voltage. That is, as long as the maximum energy of the photon is measured, the actual tube voltage of the X-ray machine can be obtained. This experiment uses high-purity germanium detectors for measurement. High purity germanium detectors have the advantages of high energy resolution and wide detection range [11, 12]. The photon energy at the end of the spectrum and the count was fitted to obtain the maximum energy of the photon (Figs. 3 and 4).

4. Measurement of the relationship between tube voltage and fluorescence intensity

Here, two sets of radiators were measured using PTW 30013 ionisation chamber and UNIDOS (Table 3).

For k-fluorescence radiation field

\[
K = N_K \times I \times N_{PT}
\]  

(1)

For temperature pressure correction

\[
N_{PT} = \frac{273.15 + T}{273.15 + 20} \times \frac{101.325}{P}
\]  

(2)

For a single uncharged particles at a particular point of kerma can also use the

\[
K = \Psi \left( \frac{\mu_i}{\rho} \right)
\]  

(3)

Get formula (4) according to formula (1), (2), (3)

\[
\Psi = (NK \times I \times N_{PT}) \left( \frac{\mu_i}{\rho} \right)
\]  

(4)

In the formula, \(N_K\) is the ionisation chamber calibration factor, and \(I\) is the ionisation current measured by ionisation chamber, the \(N_{PT}\) is the temperature and pressure correction factor [13, 14].

It can be seen that the photon fluence is proportional to the ionisation current, so only the relationship between the tube voltage and the ionisation current can be measured to determine the relationship between the tube voltage and the fluorescence fluence (Figs. 5 and 6).

### Table 1 Measurement of ionised charge at the same tube voltage and tube current

| Number | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| charge | 9.98| 10.05| 10.19| 10.18| 10.19| 10.2| 10.21| 10.18| 10.2| 10.18 |
| standard deviation difference | 0.08% |

### Table 2 Tube voltage measurement result

| Display voltage, kv | Actual voltage, kv | Relative deviation |
|---------------------|--------------------|--------------------|
| 40                  | 39.773             | 0.57%              |
| 60                  | 59.874             | 0.21%              |
| 80                  | 79.974             | 0.03%              |
| 100                 | 99.818             | 0.18%              |
| 120                 | 119.918            | 0.07%              |
| 140                 | 139.761            | 0.17%              |
| 160                 | 159.862            | 0.09%              |

### Table 3 Two sets of radiator parameters

| Radiator  | Secondary filtration | \(K_{\alpha 1}/K_{\alpha 2}\)/keV | \(K_{\beta 1}/K_{\beta 2}\)/keV |
|-----------|----------------------|----------------------------------|---------------------------------|
| Cd        | Ag                   | 23.17/22.98                      | 30.97/30.63                     |
| Cs2SO4    | TeO2                 | 26.1/26.64                       | 34.99/35.82                     |
By changing the different voltages, different ionisation charges were obtained, and measurements were made five times at the same voltage and the average was calculated. Obtain the following figure by fitting. Data fitting when the radiator is cd.

Through analysis, it can be seen that the ionisation current and the tube voltage are not linearly related. At 60 kV, the ionisation current begins to increase. At 100 kV, the ionisation current is the largest. When it exceeds 100 kV, the ionisation current will slowly decrease.

Analysis: The fluorescence yield and the tube voltage of the X-ray machine are not linear. The relationship between the two is complex and needs further verification (Figs. 7 and 8).

To further verify, change the radiator. Fit the data for Cs2SO4. By comparison, the ionisation current begins to increase at 75 keV, and the ionisation current reaches its maximum at 100 keV. When the tube voltage exceeds 100 kV, the ionisation current begins to decrease (Tables 4 and 5).

### Analysis

As the higher the voltage, the greater the power of the optical engine, the more photons generated, the higher the voltage the energy generated by the energy of the photon, making the secondary filter similar to Kα, Kβ absorption cross-section, making the secondary filter Kβ is not significant relative to Kα, resulting in decreased fluorescence purity. When the purity of Kβ is not high, an additional filter will be placed at the exit of k-fluorescence to increase the purity of kα. In order to accurately obtain the thickness of the additional filter, it is necessary to know the intrinsic filtration of the X-ray machine and the k-fluorescence device. Inherent filtering. Intrinsic filtration is an important parameter for X-ray optomechanical quality control, directly affecting the quality of image imaging and radiation dose. K-fluorescence yield and tube voltage are not a simple linear relationship (Figs. 9 and 10).

### 5 Intrinsic filtration measurement

The X-rays generated by using the k-ray fluorescence device usually have rays such as Kα, Kβ, and L. In order to obtain higher...
purity $k$ rays, a primary filter made of Al is usually used at the exit port of the optical fibre to filter out low energy. Useless X-rays and a secondary filter with different materials behind the radiator to reduce the $k_{\beta}$ and $L$ lines. Intrinsic filtration is usually measured by half-value layer method, linear extrapolation method, double-detector measurement method etc. [15].

5.1 X-ray machine’s inherent filtering measurement

The inherent filtering of the X-ray machine includes the light pipe glass, oil, window material, and other X-rays filtering.

According to ISO 4037, it is recommended to use the half-value layer measurement [16], using an Al absorber with a purity of 99.99%, determined at the first half-value layer at 60 kV without additional filtration (Figs. 11–13).

During the test, the 30013 ionisation chamber is placed 120 cm out of the fluorescent exit. Al filter material placed on the fluorescent light outlet 60 cm, the distance between the filter material and the ionisation chamber is required to be more than five times the diameter of the radiation field at the ionisation chamber, so the beam is required to achieve the conditions of the near-narrow beam. This article uses a 2-mm diameter diaphragm (Figs 14–17).

During the experiment, the radiator, primary filter, and secondary filter were all removed, and the thickness of the Al was continuously changed. The X-ray generated by the x-ray machine was measured using a 30013 ionisation chamber. The relationship between the thickness of Al flakes and the ionisation charge is obtained by fitting the measured data.
5.2 Intrinsic filtration measurement of k-fluorescent devices

The intrinsic filtration of K-fluorescence includes the inherent filtration of X-ray machines, the filtration of primary filters, secondary filtration materials, and other X-rays.

The relationship between the Al thickness and the ionisation charge is obtained by fitting the data.

Through the difference method, the first half-value layer is 1.53 mm. According to Fig. 20, when the first half-value layer is 1.58 mm by interpolation, the inherent filtering of the k-fluorescent device is 1.487 mm (Fig. 21).

6 Conclusion

The PTW 30013 ionisation chamber was used to measure the tube current of the X-ray machine. It was found that the X-ray tube current was stable within 1% during operation, and the tube voltage stability was within 2%, meeting the national standard GB/T12162.1-2000 requirements for reference radiation devices. The use of energy end point method to measure the voltage is safe and reliable, this method can be used to measure any X-ray machine tube voltage. The linear measurement of X-ray machine tube current shows that the radiation dose of the X-ray machine has a good linear relationship with the tube current, which verifies the accuracy of the X-ray machine. The current of the X-ray machine is stable, so the photon fluence generated is also stable. This type of X-ray machine can be used to carry out various types of detector research. The inherent filtration of the X-ray machine and the k-fluorescent device was measured, the inherent filtration of the X-ray machine was calculated to be 0.058 mm Al and the inherent filtering of the k-fluorescent device is 1.487 mm Al and providing an important reference for the same type of device.

7 Acknowledgments

This work was supported by National Key R&D Plan of China under Grant. Project Name: Research on Key Techniques for Measurement of Extreme Ionisation and Optical Radiation, Topic: Key Techniques for Low-dose-rate X-ray and γ-ray Metrology. Project Number: 2017YFF0205101.

8 References

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