Investigation of ultraviolet transmission characteristics of detecting window in ultraviolet corona inspector

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Ultraviolet (UV) corona inspector is used to detect corona according to the ultraviolet radiation of the discharge. High detecting sensitivity of the inspector requires high ultraviolet transmission property of the detecting window. In this paper, high performance JGS-1 (type name of glass) ultraviolet quartz glass is used as the inspector detecting window material and the ultraviolet transmission characteristics of the glass is studied. A new method with the smart corona detecting module to test the ultraviolet transmission parameter of quartz glass is demonstrated. The comparison results of UV spectrometer and this new method manifest that JGS-1 quartz glass has good ultraviolet transmission character and the new test method with corona detecting module is direct and feasible.

(Received March 29, 2011; accepted June 9, 2011)

Keywords: Corona inspector, Quartz glass, Transmission, Ultraviolet

1. Introduction

Recently the demand for ultraviolet transmitting materials has increased for applications in microlithography equipment, laser systems and special UV optics [1-2]. These optic systems will require the use of UV optical transmission components in the form of windows, lenses, and optical fibers so as to enable the visual inspection for any in-vessel operation. These components will be expected to maintain their transmission properties under the work condition. UV corona inspector is such an optic device which uses a sensor tube that detects radiation emitted in the corona between 180 nm to 400 nm range. There are two methods to detect corona include UV camera with image recognition technique and with UV sensor or Photon counting meter. Usually, high-performance UV corona inspector requires a transmission ratio of 80% to 90% at 200-280 nm. Quartz glass is the attractive candidates for high-performance window material for the deep UV range [3]. So it is necessary to study the UV transmission characteristics of the detecting window.

Cook and Mader have investigated the ultraviolet-VIS transmission characteristics of the laser glass doped with the metallic impurities in the ppm range [4]. The method is quite accurate, but costs long time to calibrate the equipment. Another method is using UV luminometer to test and compare the radiation intensity result with and without the window material and to obtain the transmission characteristic result. This method is very easy and convenient to use, but has quite low precision.

In this paper, we propose a new test method with smart detecting module, for which the digital filter technique and non-linear emendation function for the corona inspector are included. This method improves the test precision compared with the method with UV luminometer directly. The ultraviolet transmission characteristics by UV spectrometer and this new method is studied and compared.

2. Principle of UV corona inspector

Corona description and introduction. Corona is electrical discharge that occurs on transmission lines and sub-station components, including insulators, conductors, lines, cable terminations, bushings, and transmission line surge arresters, and can indicate faulty equipment. Corona discharge is a luminous partial discharge from conductors and insulators due to ionization of the air, where the electrical field exceeds a critical value. A high local electric field ionizes the air and causes a discharge. This process is accompanied by excitation of Nitrogen molecules, leading to emission of UV radiation. Buildup of ionization occurs only if electron is going fast enough, i.e. if electric field exceeds a critical value. Thus a problem or defect in a component creating a local high electric field will show corona activity. Some molecules are not ionized but excited–emitting photons on relaxation. Besides generating audio noise and radio interference, corona and arcing on power lines and substations accelerate degradation of various grid components and can indicate a number of factors which may cause an outage and/or safety issue.

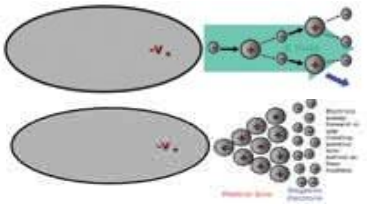

Fig. 1. Principle of corona discharge.

Fig. 2 shows the typical corona and its images. For the inspection and detection of corona discharge and arcing on overhead transmission lines and in substations, UV cameras are specifically designed for use in power transmission, substations and high voltage applications, these cameras can also detect other sources of UV including leakage from fluorescent lights, tungsten halogen lamps, alcohol and brush fires and can be able to visualize corona in full daylight without being affected by sun radiation. Whether a discharge is on an arcing horn, on a corona ring, on an end fitting of a polymer insulator or on the cap of a porcelain insulator etc… can easily be revealed by an optical device like a corona camera.

Corona on bus bar Corona source pinpointed - hole on bus bar Corona pinpointed on glass insulator

Fig. 2. Corona images.

Corona Inspector Principle. The detecting window, the sensor of corona inspector determine the detected spectrum band of corona, and the spectrum bands are the characteristic specific frequency signals of corona. According to the judge strategy of the detecting system, the sensor will generate corona alarm when it detects the corona spectrum. A UV corona inspector can uses a sensor tube that detects the UV radiation of corona. It is important to note that UV radiation from the sun that reaches earth starts at 2800 angstrom. If the inspector has a wide range then it will be triggered by the sun's rays, which means it is only suitable for indoor use. So the window of corona sensor is quite important, it can filter the unwanted spectrum band and choose the spectrum required by the sensor. Virtually all coronas emit radiation include the band (180 nm-280 nm), while the sun's radiation of these bands is absorbed by the earth's atmosphere. The result is that the UV corona inspector should be solar blind. The implication of this feature is that the inspector can be used indoors and outdoors. In response to UV radiation within the narrow band from the corona, the inspector generates a series of pulses that are converted by the inspector electronic circuits into an alarm output. And the UV inspector is sensitive to most coronas, UV inspectors are the most flexible general purpose optical corona inspectors available. They are fast, reliable, having few false alarm sources and responding to any corona. They are better than UV cameracorona inspector and the infrared inspector.

Quartz glass material

Quartz glass has special functions as high mechanical intensity, good anti-hotness character, steady chemistry property, and small electric loss. Most of all it has excellent optical function. It has good transmission property from infrared to UV rays, so it is an ideal optic material and widely used in microelectronics, precise optics and MEMS (micro- electromechanical system). UV quartz glasses are attractive candidates for high-performance window materials for the deep UV range. Vacuum UV quartz glass is produced by chemical vapor deposition synthesis technique based on pure SiCl4 material. The main producing techniques are gas smelting technique, power synthesis technique, sol-gel technique, and plasma smelting technique [5]. However the actual UV transmission of glass is frequently limited by extrinsic absorption of trace impurities introduced by raw materials and the possible contamination from the melting technique and method of processing used. Glasses melted under reducing conditions in carbon crucibles have much higher UV transmission than glasses melted under oxidizing conditions in platinum crucibles. The increase of the UV transmission is mainly attributed to a reduction of Fe^{3+} and Fe^{2+} due to carbon crucible melt interaction [6].

We chose the JGS-1 quartz glass produced by the Quartz and Special Glass Research Institute of China Building Materials Academy as the inspector window. For any optic device, the window material is quite importance. The UV transmission parameter of common glass is very low and can not be the window material. While the materials as quartz glass, sapphire and MgF_2 are fit to be window materials for UV optic device. And quartz glass is the best material for Te-Se UV cathode. The UV transmission technique parameters given by the glass research institute are list in Table 1. The quartz glass is JGS-1 vacuum UV optical glass, and the application spectrum range is 185 nm to 2500 nm, which produced by synthesize CVD method.

Table 1. Ultraviolet transmission parameters.

Glass name	Type No.	Thickness/mm	Spectrum/nm	Wavelength/nm	T/%
Vacuum UV optical glass	JGS-1	1	185-2500	185-200	87
				300-800	91
				800-2500	90

UV Transmission test principle

The output pulse number and voltage value of UV corona inspector are related with light wavelength, radiation power and the circuit. The optical current and the sensitivity of the inspector are proportional to the radiation. The sensitivity of UV corona inspector relies on the output pulse number. The pulse number is proportional to radiation intensity. Most UV tubes response the thunder or electric discharge and generate pulse outputs automatically. So it is essential to process the output signal with filters. Also in order to test the transmission and apply the linear proportional relation of the radiation and output pulses, the inspector must be linear. But the traditional UV corona inspector has the cross sensitivity which caused by the interfering parameters, such as the temperature change or the voltage change. Such interfering parameters make the system unsteady and non-linear. Recently the smart detecting module can realize the on line calibration and amend the input-output characteristic to linear so as to improve the precision of the whole system. The smart corona detecting module named ZJM6 adopts digital filter technique to filter out the background noise (self-pulse, thunder and discharge), and it has the non-linear emendation function. The system diagram is shown in Fig. 3.

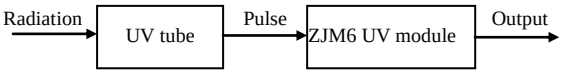

Fig. 3. Diagram of the smart UV detecting system.

The UV tube is used to transform UV radiation into electric signal and generates the pulses. The ZJM6 smart module reshapes the pulses, filters out the background noise and realizes the non-linear calibration. Li has studied the relation of light spectrum auto-measuring system and given the result as follows [7]:

$$f(K) = k(K)E(K)T(K) \tag{1}$$

Where f(K) represents the output of inspector, E(K), T(K) and k(K) are the spectrum of light source, the transmission of window glass and the spectrum response constant of inspector, respectively. For the same working condition where E(K) and k(K) keep the value, it is obvious that the output signal of corona inspector is linear proportional to spectrum response output:

$$f(K) \propto T(K) \tag{2}$$

UV Transmission test experiment

UV transmission parameter is the key characteristic of quartz glass, Hosono and Ebeling had carried out investigation of UV transmission by EPR-spectroscopy [8-9]. In this paper we have applied two methods to test the UV transmission of quartz glass. The first method is using UV spectrometer, the second method is using UV inspector with ZJM6 smart module which is initially proposed in this paper. Compare the output frequency signals and obtain the UV transmission results. The detecting module applies the neural network model to realize the non-linear cakibration and auto-emendation function for the inspector. The test accuracy is improved compared with using UV luminometer and it is more feasible than using spectrometer. The test results of spectrometer and the smart detecting module are compared with the technique parameters given by the glass research institute.

UV Spectrometer Test Method. The optical absorption spectra of quartz glass was obtained using a UV-260 spectrometer of which the test wavelength range was from 190 nm to 900 nm, the light source was deuterium lamp and its power was 50w. UV transmission tests were made on JGS-1 quartz glass and its thickness is 1 mm. For the test experiment, the UV spectrum band was set at 190 nm to 350 nm, the compared sample was air. Fig. 4 manifests the T-^curve of relationship between the UV transmission parameter and the UV wavelength.

The test result manifests that the UV transmission is coincident with the technique parameters given by the glass research institute.

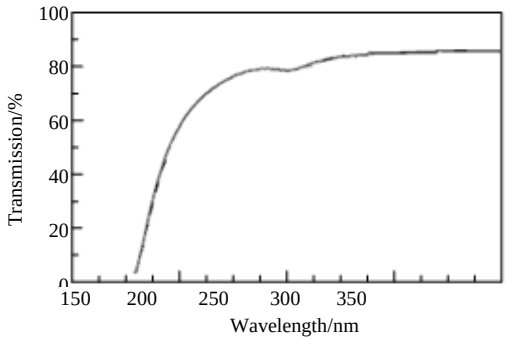

Fig. 4. Vacuum ultraviolet transmission spectrum.

Fig. 5. Setup of ultraviolet transmission test.

UV Inspector Test Method. The method is using UV inspector to test the response signals of the standard corona lamp according to the GB test standards, and comparing the response outputs of the inspector at the conditions with and without JGS-1 quartz glass. The smart detecting module is used to calibrate the non-linear characteristic of the UV corona inspector. The setup of the test experiment is shown in Fig. 5.

The frequency output signal for the standard lamp was tested by UV 1753 corona inspector and ZJM-6 detecting module at 2m distance. The output signal is recorded by Frequency Counter HC-F100L and listed in Table 2. Then put the JGS-1 quartz glass at the front of the UV 1753 inspector window, and test the output signal again. As the glass absorbs UV radiation, the test result would be different from the first time. Record the results and compare the difference of both the experiments. The corona of the lamp twinkles, so the output signals also vibrate at a certain range. Record the maximum and minimum values, and list in the table. fDmin, fDmax, fJmin and fJmax stand for the minimum output for direct test, the maximum output for direct test, the minimum output for test with JGS-1 glass and the maximum output for test with JGS-1 glass respectively.

Table 2. Comparison of output signal.

Sample number	1	2	3	4	5	6	Mean value
f_{Dmax}/Hz	211	217	222	231	222	210	218.83
f_{Dmin}/Hz	170	184	183	178	171	175	176.83
f_{Jmax}/Hz	194	186	182	189	182	197	188.33
f_{Jmin}/Hz	159	146	158	163	157	153	156.00

The differences of the outputs are caused by the UV absorption of JGS-1 quartz glass. As the spectrum response ratio is proportional to the luminous flux and the detecting range of the inspector is from 185 nm to 260 nm, and the output signal of ZJM-6 corona detecting module is linear proportional to the UV transmission radiation. According to Eq.(2), the expression of UV transmission is below.

$$T = f_J / f_D \tag{3}$$

where T manifests the transmission of JGS-1 quartz glass, inspector, fD and fJ are the test results without and with JGS-1 quartz glass respectively. From the data recorded in experiments, we can calculate out the UV transmission parameter of JGS-1 quartz glass at 185 nm to 260 nm is equal to 87.027% which is close to the technique parameters given by the glass research institute and the result tested by UV spectrometer. Also the results manifest that the method we proposed is useful and more feasible.

3. Conclusions

UV transmission parameter is an important characteristic for UV detecting window material. The UV transmission of JGS-1 quartz glass is studied by UV spectrometer and a new test method with smart detecting module which was first proposed in this paper. The comparison of the test results manifest that this new test method is useful and it is more feasible than with UV spectrometer, also its precision is better than the method with UV luminometer. The test results are coincident with the technique given by quartz glass research institute. Although this method is more feasible and fit the common application, its precision is lower than UV spectrometer.

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