Characteristic band of arcing between pantograph-catenary system in urban rail detection system by UV method

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Abstract. One of the key steps for arcing detection by UV method is to select characteristic bands reasonably. In this paper, the spectral data of arcing between the pantograph and contact line is obtained by experimental method. It can be seen from the results that although the external factors of each arcing are not exactly the same, the spectral distribution seems similar. The positions of several peaks are basically the same, and the band of 275-285 nm is particularly prominent in the solar-blind area. In the six arcs, the proportion of integral value of radiation intensity is relatively stable, accounting for about 18%. The integral value in the whole arcing increases linearly with the rising intensity of arcing. Therefore, the waveband between 275-285 nm can be determined as the characteristic one for arcing detection system.

1. Introduction
The phenomenon of arcing caused by contact-loss between pantograph and catenary system has been paid more and more attention by engineers and technicians in the electrified railway industry. Although arcing can keep current supplied to the train continuously, it will make the transformer on-board suffer from high frequency oscillation overvoltage, and it may also erode and shorten the service life of the contact line, in severe cases, serious accidents may occur [1].

With the increasing speed of the train, the arcing problem becomes more and more prominent, which has become one of the core problems to be solved with the rapid development of electrified railway. There are many reasons for arcing, such as unsmoothness and vibration of contact wire, vibration of pantograph and track irregularity [2]. Therefore, the phenomenon of arcing cannot be eliminated completely, but the location, intensity and duration of arcing can be detected and calculated by appropriate methods to provide the basis of the maintenance to the related workers. The current detection methods based on electromagnetism, thermal and acoustic of arcing have some disadvantages, solar-blind method based on ultraviolet ray of the arcing has been paying much attention because it can avoid the electromagnetic interference from the contact line and interference from ultraviolet in the sunlight effectively. Japan and Italy took the ultraviolet band of 200-240 nm and 175-195 nm as the characteristic signals respectively, and Cheng M. of Southwest Jiao Tong university in China used the waveband of 240-260 nm as the characteristic one to detect the arcing between pantograph and catenary system [3-4]. The spectral distribution of the arcing is related to the material of the pantograph slide and contact line, and is affected by the current in the contact line, therefore, it is necessary to find the spectral distribution of the arcing in the special power supply system of the urban rail transit system in China by experimental methods, so as to determine the characteristic waveband that can reflect the arcing strength accurately.
2. Materials and methods

2.1 Structure and operating principle of the arcing detection system

The hardware structure of the arcing detection system based on ultraviolet ray is shown in figure 1, the optical acquisition system of the arcing detection system is fixed on the roof of the train with its lens facing the contact point of pantograph and the contact line, and the data processing part is installed in the train carriage. An optical acquisition system equipped with a narrow-band filter allows the characteristic band of ultraviolet ray in arcing to passing through and imaging on the optical fiber at the end. The optical signal is transmitted to the PMT (photomultiplier tube) through optical fiber, PMT is a vacuum electronic device that can convert weak optical signals into electrical ones. The light signal of arcing is amplified through the multiplier pole of PMT to form a considerable electrical signal which is proportional to the optical one, and the electrical signal is sent to the data processing module for processing.

![Figure 1. Structure of the arcing detection system based on ultraviolet ray.](image)

2.2 Arcing spectrum experiment

An experimental method is proposed for the spectral range of the arcing between pantograph and contact line and the circuit is shown in figure 2, copper contact line and pantograph carbon slide with the same material as the actual is used in the laboratory. The power supply voltage is DC 1500 V which is adopted by most urban rail in China. The arcing spectrum is recorded by a spectral analyzer; the avaspec-2048-usb2 spectrum analyzer manufactured by AVANTES of the Netherlands is placed 2.25 m away from the contact point between contact line and carbon slide, the spectrum analyzer has a working wavelength range from 200 nm to 1100 nm and a signal-to-noise ratio of 200:1, its detection sensitivity and reliability is relatively high.

![Figure 2. Experimental circuit diagram of the arcing detection system.](image)

During the experiment, fix the contact line and carbon slide on the operating table and maintain the same spacial relation with actual. Adjust the fixed line clamp to make the minimum distance between them about 1 cm.

Switch on the positive and negative electrodes of the power supply, and observe whether there is an arcing phenomenon by adjusting the distance between the contact line and the slide. If not, the experimental steps should be repeated until there are 6 obvious arcs. Record and analyze the arcs with the spectrum analyzer. and find the obvious band range of the peak in the spectral distribution diagram, determine the band distribution at the highest point of the peak in the solar-blind area.

2.3 Analysis the arcing spectrum by integral method
The distribution of arcing spectrum is dispersed and complex. The arcing strength cannot be judged by the size of a certain wave crest alone. Therefore, integral method is used to analyze the radiation intensity of the arcs.

\[ G(\lambda) = \int_{\lambda_1}^{\lambda_2} W(\lambda) \cdot d\lambda \]  

In the formula above, \( G(\lambda) \) represents the integral value of the radiation intensity of arcing within a certain band, \( \lambda_1 \) is the start wavelength of the integral band and \( \lambda_2 \) is the end one, while \( W(\lambda) \) is the relative value of radiation intensity.

Formula (1) is used to calculate the integral value of the full wavelength range, the solar-blind area from 200 nm to 300 nm and the obvious peak band range in the solar-blind area, the relative integral value proportions of arcing radiation intensity in the whole arcing spectrum and solar-blind area is counted. If the integral value of the wave crest section is constant or follows a certain rule change in the solar-blind area and the entire spectral distribution, this band can be determined as the characteristic one for arcing detection.

3. Results and discussion

Urban rail transit lines usually include both aboveground and underground sections, when using UV method to detect arcing, it is necessary to find a method to avoid the interference from the sun. In nature, the sun is the most powerful source of ultraviolet radiation. The wavelength range of ultraviolet light is 10-400 nm, which is distributed between visible light and X-ray. Light whose waveband below 200 nm is vacuum ultraviolet, 200-300 nm is medium ultraviolet, and 300-400 nm is near ultraviolet. The oxygen atoms in the upper atmosphere strongly absorb the vacuum ultraviolet, so the ultraviolet radiation of this band can only be found in outer space. The ozone layer in the stratosphere has a strong absorption effect on the medium ultraviolet, and the solar ultraviolet radiation of this band barely exists in the near-earth atmosphere, so the band of 200-300 nm is called "solar-blind area" [5].

When arcing happens, the electrons or ions in contact face of the contact line and slide are excited, resulting in energy level transition. The electrons or ions in a specific material will transition from a high energy level to a low, generating light with a specific wavelength [6]. When using UV method to detect the arcing, as long as the detection characteristic band is set in the solar-blind area, the interference effect from sunlight can be successfully avoided. However, the spectral distribution is mainly concentrated in the range of a few bands. Therefore, it is necessary to find the band range with the relatively concentrated spectral strength within the solar-blind area when the arcing occurs.

The spectral characteristics of arcs obtained from the experiment are shown in Figure 3. The abscissa is the wavelength, and the ordinate is the relative value of arcing radiation intensity.

![Figure 3. Complete Spectral distribution graph of the six arcs.](image-url)
It can be seen from figure 3 that in the experimental process, the spectral distribution and strength of the six arcs are not exactly the same as the distance and the approaching speed between the contact line and pantograph slide are different each time, but it shows a basically consistent regularity. The spectrum of arcs distributes between 200-1100 nm, and the bands with higher relative radiation intensity are 275-285 nm, 300-330 nm, 384-400 nm, 420-426 nm, 540-560 nm, 578-645 nm, 760-786 nm and 815-824 nm, and the first three bands are in the ultraviolet radiation zone.

Based on the experiment, the arcing spectrum distribution in the band of 200-300 nm is intercepted and shown in figure 4. As can be seen from figure 4 that, the highest wave peak appears in the band of 275-285 nm. If the radiation intensity of this band in different situations can be verified to be stable both in the solar-blind area and the whole arcing spectrum, it can be used as the characteristic waveband in the ultraviolet arcing detection system.

Formula (1) is used to calculate the integral values of the bands in the full wavelength range of the six experimental arcs, the solar-blind area of 200-300 nm and the band of 275-285 nm where the wave peak occurs respectively. Both the proportion of the arcing radiation intensity of the wave crest in the whole arcing spectrum and the solar-blind area is calculated, and the results are listed in table 1.

![Figure 4. Spectral distribution graph of arcing in the solar-blind area.](image)

| Arcing | Integral value of 275-285 nm ($G_1$) | Integral value of 200-1100 nm ($G_2$) | Integral value of 200-300 nm ($G_3$) | $G_1/G_2$ (%) | $G_1/G_3$ (%) |
|--------|------------------------------------|---------------------------------------|------------------------------------|--------------|--------------|
| 1      | 7526                               | 905735                                | 42025                              | 0.831        | 17.9         |
| 2      | 5819                               | 875511                                | 32247                              | 0.645        | 18.0         |
| 3      | 4771                               | 795276                                | 25908                              | 0.600        | 18.4         |
| 4      | 3619                               | 745961                                | 19869                              | 0.485        | 18.2         |
| 5      | 2780                               | 729122                                | 14919                              | 0.382        | 18.6         |
| 6      | 2181                               | 695237                                | 11636                              | 0.314        | 18.7         |

In table 1, the 6 arcs are arranged in descending order of intensity. According to the data in the table, it can be seen that the relative intensity integral values of the solar-blind area and the characteristic band of 275-285 nm are also in descending order, indicating that the light intensity distribution range of the solar-blind area and characteristic band changes in the same direction with the change of arcing intensity. The results of the light intensity ratio in table 1 are shown in figure 5.
Figure 5. Intensity integral value relationship between characteristic waveband and the whole arcing. It can be seen from Figure 5 clearly that the integral value of ultraviolet radiation within the range of 275-285 nm increases with the whole rising arcing spectrum. When the arcing changes, although the proportion of the integral value of this band is not constant, it increases with the rising arcing. and it can be seen from table 1 that the relative integral value of the radiation intensity of the 275-285 nm band in the arcing is basically constant in the whole solar-blind area, the distribution is around 18%. Therefore, it can represent the ultraviolet radiation intensity of the solar-blind area.

4. Conclusions

To select the characteristic waveband of solar-blind area reasonable of the arcing detection system of the pantograph and catenary system is very important, it can not only improve the accuracy, but also avoid the interference from sunlight effectively.

In this paper, the spectrum distribution of the arcing between pantograph and contact line in urban rail transit is analyzed by means of experiments, and the conclusions are as follows:

(1) Under the condition of the same voltage, the same material of contact wire and the carbon slide, although the distance between the contact line and the carbon slide and the approaching speed are different when arcing happens, the spectral distribution is similar, and the location of wave crest is basically the same.

(2) In the range of 275-285 nm band, there is an obvious wave crest in the arcing spectrum.

(3) After integrating the relative strength value of arcing, it can be seen that the integral value of 275-285 nm band occupies a stable proportion in the ultraviolet band in the whole solar-blind region. It is about 18%. Its proportion in the complete arcing spectrum increases when the whole arcing intensity increases, as can be seen from figure 5, the relation is basically linear.

Therefore, the wave band from 275 to 285 nm, which distributes in the solar-blind area can reflect the strength of the arcing. It is reasonable that the characteristic waveband be used in the arcing detection of urban rail power supply system. The experimental method and the analysis process in this paper can provide a certain basis for other similar problems.

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