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Original research article

Improve atmospheric visibility accuracy with the divergence angle correction of the probe beam

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ABSTRACT

The probe beam is the important part of the visibility meter. And the divergence angle size of the probe beam affects the accuracy of visibility. In the paper, the relation between the divergence angle and the visibility relative error was established by the experiment model. The aerosol generator produced different concentration atmosphere, which was measured as atmospheric sample under the different visibility. The relationship between the divergence angle of the probe beam and the different atmospheric samples was established. The detection values and correction function were obtained at different divergence angles under various atmospheric samples. The experimental result shows that the divergence angle of the probe beam affects the visibility measurement. And the larger the divergence angle is, the greater the measurement error is. The measurement of the divergence angle must be corrected. Using the measurement method with the divergence angle correction, under the low visibility conditions, the relative error of the visibility is reduced from 25% to 10% at least, in the divergence angle range of 25mrad. When the allowable error is 5%, the allowable value of the divergence angle is increased by one time.

1. Introduction

According to the definition, visibility could be presented by the meteorological optical visual range. Meteorological optical visual range refers to the distance that the luminous flux weakens to 5% of initial value through the atmosphere, and the flux comes from the parallel beam of incandescent light which color temperature is 2700 K [1]. In the definition, there is explicit requirement that the probe beam should be parallel. For transmissive visibility meter, when the probe beam is parallel, the transmittance T could be calculated that $T = \frac{I}{I_0}$, in the detection channel [2]. And the visibility $R \propto \frac{1}{\ln T}$. The actual beam is not strict parallel in the measurement channel due to scattering, especially multiple scattering effects [3–5]. The visibility basic equation [6], Lambert-Beer law $I = I_0 e^{-\beta L}$, has ignored multiple scattering effects. β is extinction coefficient, and L is distance of measurement channel. When βL gets to a certain degree, multiple scattering effects cannot be ignored[7], which reduces the accuracy of Lambert-Beer law. Deepak and Zardecki had studied the relationship between the multiple scattering correction and the field of view in detail[8]. For scattering visibility meter, the receiving value is also affected by the emission angle of probe beam and the receiving field angle of detector. Xiao S et al. [9] used the combination of lens and fiber to constrain the viewing angle. The measurement value was near double compared to the unconstrained.

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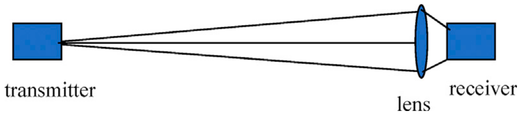

Fig. 1. Transmission visibility measurement device.

However, due to the presence of the probe beam divergence angle [10–16], the detector's sampling volume changes, which will cause the detection value to change. At the same time, during the installation and movement of the visibility meter, the divergence angle of the light source is likely to change. It will affect the detection value [17,18]. In order to study the influence of divergence angle on visibility, we took the different concentration aerosol as the atmospheric sample, and measured them. The visibility measurement model with different divergence angle was established. The accuracy of visibility measurement was improved by correcting the divergence angle.

2. Principle

In the transmission visibility measuring device [19,20], the change of the position and the size of the divergence angle will cause the collimation error of the receiver [21,22]. When the divergence angle is too large, the spot cannot fall in the receiving plane completely. It will make the measurement error. When the collimation system corrects the collimation error in real time and the receiver has the lens, the spot can be ensured to fall in the center of the detector, and the collimation error is the smallest. From the aspect of the detector receiving light intensity and particle scattering, the scattering particles increases with a certain divergence angle. The secondary scattering and multiple scattering of the particles cause the widening of the brightness direction. Especially in the case of low visibility, multiple scattering cannot be ignored and its effect is significant. The impact on the detector receiving value also tends to be significant [2,3].

In the transmission visibility measurement device as shown in Fig. 1, the probe beam divergence angle affects the receiver to determine the volume of the sample directly. At the same time, the detection value is also affected by wavelength, medium particle size, density, optical thickness and other factors. For a random medium volume V, in the direction of e_S, a certain point r, its radiation brightness can be divided into two parts. One part is the brightness of the incident radiation in the direction, known as the reduction brightness. The other part is the contribution of other scatters in the direction of e_S, known as the diffuse brightness. For the transmission visibility measurement device, the radiance received by the detector is the sum of the average reduced brightness and the average diffuse brightness in the whole range of the solid angle. They are

$$U_{ri}(r) = \frac{1}{4\pi}\int_{4\pi} L_i(r_0, e_S)e^{-\tau(r)}d\omega \tag{1}$$

$$U_d(r) = \frac{1}{4\pi}\int_V \left[\gamma \int_{4\pi} p(e_S, e_S{}')L_i(r_1, e_S{}')d\omega' + \varepsilon(r_1, e_S{}')\right] \frac{\exp[-\tau(r)+\tau(r_1)]}{|r-r_1|^2} dV_1 \tag{2}$$

The size of the probe beam divergence angle changes the volume of the medium V, which affects the average diffuse brightness directly, and also affects the detector's receiving value. However, when using Lambert-Beer law to calculate the visibility

$$R = \frac{L\ln\varepsilon}{\ln T} = \frac{L\ln\varepsilon}{\ln\frac{I}{I_0}} \tag{3}$$

Where $L\ln\varepsilon$ is the constant, I_0 is emitting light intensity, $I$is receiving light intensity. I reflects the reduced brightness of the light source only. This needs to be measured at a very narrow angle in the direction of light advance [4,5]. When the probe beam has a certain divergence angle, the larger the angle, or the larger the size of particles in the detection channel, the greater the proportion of the diffuse brightness received by the receiver. Thus, it is necessary to correct the detector receiving value by the relationship between the divergence angle and the radiation brightness when calculate the visibility with Lambert-Beer's law.

For transmissive measurement, the optical power can be analyzed by the relationship between the divergence angle of probe beam and the receiving value of the optical power. It is expressed as,

$$I_t{}' = I_t f(\theta) \tag{4}$$

where $I_t{}'$ is the theoretical value, I_t is the measured value. The visibility is

$$R = \frac{L\ln\varepsilon}{\ln T} = \frac{L\ln\varepsilon}{\ln\frac{I_t{}'}{I_0}} = \frac{L\ln\varepsilon}{\ln\frac{I_t f(\theta)}{I_0}} = \frac{L\ln\varepsilon}{\ln\frac{U_t f(\theta)}{U_0}} \tag{5}$$