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Agenda item [[2]](#footnote-2) (from agenda)

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Working Group WG1

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Measurement and Calculation of Luminous Intensity of Aids to Navigation Light

# 1 SuMMary

China Maritime Safety Administration has conducted in-depth research on measurement technology of luminous intensity of AtoN light since 2019 by referring to IALA R0203, R0204, G1135 and CIE standards, and developed a complete traceable and operational method for measuring the luminous intensity of AtoN light, which gave detailed guidance for the measurement of luminous intensity of AtoN light.

The following is a complete measurement and calculation method of luminous intensity of AtoN lights developed by China. There are ten specific technical requirements, laboratory environmental conditions, the general technical requirements of the goniophotometer, spectral correction factor calculated by strict alternative method, technical requirements of spectroradiometer, criteria for judging the completion of AtoN light warm-up, determination of measurement distance, measurement of luminous intensity versus angle, measurement of luminous intensity of steady light, three measurement methods of effective intensity of rhythmic light, measurement of luminous intensity of array AtoN light, which have certain reference value for improving R0203.

In order to facilitate discussion and understanding, this input document presents the whole standard measurement and calculation of luminous intensity of AtoN light.

## 1.1 Purpose of the document

This document is intended for the provision of reference to the commencement of the task of developing R0203 on light measurement into a guideline.

## 1.2 Related documents

IALA Recommendation R0203(E-200-3) - Marine signal lights, part 3 - Measurement

IALA Recommendation R0204 - Marine signal lights - Determination and calculation of effective intensity

IALA Guideline G1135 - Determination and calculation of effective intensity

CIE 229:2018 Groundwork for Measurement of Effective Intensity of Flashing Lights

# 2 BackgrounD

IALA Recommendation R0203 on light measurement provides comprehensive technical suggestions for the photometric and colorimetric measurement of AtoN light, which are general principles to be followed by the competent technical authorities of all countries in the world. If some specific guidance with wider universality and stronger operability can be added in R0203, its practical value will be improved.

The measurement and calculation of luminous intensity of AtoN light developed by China Maritime Safety Administration is a specific and detailed measurement method based on the actual application requirements and the technical standards of international authoritative institutions such as IALA and CIE. A number of elements in this method are supplements to R0203.

At present, IALA plans to develop R0203 into a guideline in the next task plan. This input document can provide a reference for this task and will effectively improve the development level of the new guideline.

# 3 DiscussioN

## 3.1 Measurement Principle

### 3.1.1 Measurement Principle of Luminous Intensity

According to the Photometric Distance Law proposed by Lambert in 1760, the illuminance is inversely proportional to the square of the distance to the point light source. In the case of oblique light, the illuminance is directly proportional to the cosine of the angle between the beam direction and the normal of the illuminated surface. The illuminance on the receiving surface of the illuminometer is determined by Equation 1.

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Where:

 is the illuminance on the receiving surface of the illuminometer, whose standard unit is Lux ( lx ),

 is the luminous intensity of the test AtoN light, whose standard unit is candela ( cd ),

 is the distance from the light source center of the test AtoN light to the receiving surface of the illuminometer, whose standard unit is meter ( m ),

 is the included angle between the beam in the measured direction of the AtoN light and the normal of the receiving surface of the illuminometer.

When  equals to zero, Equation 1 becomes:

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The luminous intensity of the AtoN light is obtained by measuring the illuminance value and then determined by Equation 2.

### 3.1.2 Calculation of Effective Intensity of Rhythmic Light

The effective intensity,  ,of rhythmic light is calculated by convolution method according to Modified Allard Method (MAM), i.e. Equation 3.

(3)

Where:

 is the instantaneous luminous intensity of the flash a a time t, whose standard unit is Lux ( lx ).

 is the visual system response function, which is determined by Equation 4:

(4)

Where:

 is the visual time constant, ( blue light ), ( non blue light ).

When a group of flashes make up a flash character, the reported effective intensity shall be that of the lowest individual flash effective intensity calculated according to Equation 4 in the group.

## 3.2 Measurement Requirements

### 3.2.1 General Requirements

(1) Laboratory Environmental Conditions

Unless otherwise specified, the laboratory environment shall meet the following requirements:

1. The ambient temperature shall be 25 ℃ ± 3 ℃.
2. The ambient relative humidity shall be 10% ~ 65%.
3. No smoke, dust, water vapor, mechanical vibration, electromagnetic and light interference affecting the measurement accuracy.
4. The laboratory shall be a dark room environment, in which the walls shall be painted with matte black paint, and non reflective measures shall be taken for measurement equipment, baffle and other measurement accessories.

(2) Power Supply Requirements

The test AtoN lamp shall be operated at rated voltage or current.

For the AC powered AtoN lamp, the voltage of an AC power supply (RMS voltage) applied to the test AtoN lamp shall be regulated to within ± 0.2% under load. If the rated value is within a range, the middle value shall be taken. The AC power supply shall have a sinusoidal voltage waveshape at the prescribed frequency (typically 60Hz or 50Hz). The total harmonic distortion or RMS summation of harmonic components shall not exceed 3% of the fundamental frequency.

For the DC powered AtoN lamp, the voltage of an DC power supply voltage (instantaneous voltage) applied to the test AtoN lamp shall be regulated to within ± 0.2% under load. The AC component (RMS value) or ripple coefficient of the DC voltage shall not exceed 0.5% of the DC voltage.

### 3.2.2 Measurement Equipment

(1) Goniophotometer

The goniophotometer usually includes a mechanical mechanism (i.e. rotating worktable) for supporting and positioning the measured AtoN lamp, photometer, other necessary sensors and measurement signal processing system. The photometer can also be replaced by spectroradiometer, which measures the spectrum and calculates the photometric value by integration. The goniophotometer shall meet the following general technical requirements:

1. With good stray light elimination performance, the goniophotometer is placed in the darkroom, or the measuring light path is shielded by the light shade tube without stray light interference from the outside.
2. Calibrate the goniophotometer with a luminous intensity standard lamp traceable to the national metrology institution.
3. The distance between the center of the rotating table and the receiving surface of the photometer shall meet the requirements of 3.2.3 (3). If necessary, a photometric guide rail shall be installed.
4. The photometer used shall meet the requirements of 3.2.2 (2), and if the spectroradiometer is used, it shall meet the requirements of 3.2.2 (3).
5. The rotating table shall adopt A-α measurement geometry as shown in Figure 1, and A typical goniophotometer is shown in Figure 2. The angle range should meet: plane A -180° ~ 180°, α -90° ~ 90°; The angle accuracy should be within ±0.05°; The minimum angle step shall not be greater than 0.1°.

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*Figure 1 The A-αmeasurement geometry*

Where:

1 is the measured AtoN light.

2 is the third axis of AtoN light.

3 is the second axis of AtoN light.

4 is the first axis of AtoN light.



*Figure 2 The schematic diagram of A-αgoniophotometer*

Where:

1 is the measured AtoN light.

2 is the photometer.

(2) Photometer

The mismatch coefficient of the relative spectral responsivity of the photometer shall be less than or equal to 6%. For the white light source being measured, although it is strongly recommended, it is not necessary to correct the spectral mismatch error. For the coloured light source being measured (such as red, green and blue monochromatic light), the spectral mismatch error must be corrected.

The spectral mismatch correction is by use of a spectral correction factor(SCF), as determined by Equation 5. The corrected photometric value is calculated by multiplying the measured photometric value by the SCF. When measuring different colors of AtoN lights with two or more light colors, the SCF of the corresponding color shall be used to correct the photometric value.

(5)

Where:

 is the spectral power distribution of the test lamp, which can be measured by the spectroradiometer described in 3.2.2 (3).

 is the spectral data of the CIE illuminant A.

 is the photopic luminous efficiency function of the standard observer.

 is the relative spectral responsivity of the photometer.

If the SCF cannot be obtained, a strict alternative method can be used to obtain the correction factor: a calibrated spectroradiometer and a photometer is used to measure the photometric value of the AtoN light respectively in the same position and with the same luminous state of the measured light source, then the correction factor is calculated according to Equation 6. The corrected photometric value is obtained by multiplying the measured photometric value by the correction factor. For AtoN lights with two or more colors, the photometric correction shall be carried out for each color separately.

 (6)

Where:

 is the photometric value of the AtoN light measured by a calibrated spectroradiometer.

 is the photometric value of the AtoN light measured by a photometer.

 is the correction factor of the photometer.

The measurement sensitivity of the photometer shall be higher than 0.001lx and the linearity shall be higher than 1%.

There are two types of photometer:

1. A conventional photometer, the average value of the modulated light obtained when measuring the modulated light, should have a low modulated light dependence, with the frequency flash index less than or equal to 0.1% at 100Hz and less than or equal to 5% at 40 Hz and 100000 Hz.
2. A fast photometer, which measures the instantaneous photometric value with a response time not greater than 10 μs and a sampling frequency at least 1 kHz.

(3) Spectroradiometer

The wavelength range of the spectroradiometer should cover at least 380nm-780nm, the bandwidth (half-peak bandwidth) should be no more than 5nm, the wavelength accuracy should be higher than ±0.5nm, and the photometric linearity in the visible band should be higher than 1%.

### 3.2.3 Measurement Preparation

(1) Installation of AtoN Light

The test AtoN lamp is fixedly installed on the rotating workbench to make sure the photometric center of the AtoN lamp coincides with the rotating center of the rotating workbench. In addition, it shall be ensured that the photometer is at the same height as the rotation center of the workbench and aligned with the photometric center of the test AtoN lamp.

The photometric center of a device shall be at the center of the stereograph of its luminous surface profile.



*Figure 3 Installation diagram*

Where:

1 is the rotating workbench of goniophotometer.

2 is the photometric center of AtoN lamp.

3 is the AtoN lamp.

4 is the baffle.

5 is the photometer.

For Array AtoN light (AtoN light with 2 or more obvious gap light-emitting areas), when the luminous intensity is measured with a goniophotometer, each light-emitting area shall be measured separately if the measurement distance in 3.2.3 (3) can’t be met. The photometer should be aligned with the photometric center of each light-emitting area during measurement, and the measurement datas of each light-emitting area shall be reported.

(2) AtoN Light Warm-up

Before measurement, the measured AtoN lamp shall be operated under the specified ryhthmic character for a long enough time to achieve photometric, electrical stability and temperature balance. The AtoN lamp shall be operated under the conditions specified in 3.2.1 (2) during warm-up. The photometer is used to continuously monitor the output of the measured AtoN light, which can be determined as stable when the following conditions are met:

1. Under the steady light state, the photometric value is measured every 5 minutes, and the relative variation of three consecutive measurements is less than 0.5%.
2. In the rhythmic light state, a fast photometer is used to measure and calculate the effective intensity according to 3.1.2 every 5 minutes, The relative variation of three consecutive times is less than 0.5%.

When the test AtoN lamp is switched to a different light character or color for the subsequent measurement, the stability shall be judged again according to the above conditions before measurement. Record the stabilization time for each measurement.

(3) Measurement Distance

The distance between the photometric center of the AtoN lamp and the photometer shall comply with the Photometric Distance Law described in 3.1.1, and the distance from the AtoN lamp to the spectroradiometer is not required.

The measurement distance should be determined by the following methods. When the AtoN light is in the steady light state, the initial distance between the photometer and the AtoN light is 20 times of the largest dimension of the test AtoN lamp. Then, move the photometer so that the distance increases by 1m each time, and measure the luminous intensity at each distance. When the relative variation of three readings (maximum - minimum) /(the last value) is less than 0.5%, it is considered to meet the Photometric Distance Law.

## 3.3 Measurement Method

### 3.3.1 Measurement of Luminous Intensity Versus Angle

(1) AtoN Light Setting

The measurement of luminous intensity versus angle is generally measured under the steady light state.

(2) Measurement of Luminous Intensity Versus Angle of Pencil Beams

The rotating workbench of the goniophotometer shall carry out rotating scanning in the horizontal direction and vertical direction respectively at an angle interval of no more than 0.1 ° from the reference axis, and the scanning range shall not be less than 2 times of the corresponding nominal beam divergence angle. The photometer collects and extracts the photometric signal at each angle and measures the illuminance value ......, ,,,,,,,......, and calculates luminous intensity at each angle according to Equation 2 ......, ,,,,,,,......., and draws horizontal luminous intensity distribution profile and vertical light intensity distribution profile respectively.

(3) Measurement of Luminous Intensity Versus Angle of Fan Beams

The rotating workbench of the goniophotometer shall carry out rotating scanning on the horizontal datum plane at an angle interval of no more than 1 °, and the scanning range shall not be less than the nominal beam horizontal divergence range of the measured AtoN light. The photometer collects and extracts the photometric signal at each angle and measures the illuminance value ,,,......, and calculates luminous intensity at each angle according to Equation 2,,,,......., and draws horizontal luminous intensity distribution profile of fan beam. The rotating workbench of the goniophotometer shall carry out rotating scanning in the vertical direction at an angle interval of no more than 0.1 °from the reference plane, and the scanning range shall not be less than 2 times of the nominal beam vertical divergence angle of the measured AtoN light. The photometer collects and extracts the photometric signal at each angle and measures the illuminance value ......, ,,,,,,,......, and calculates luminous intensity at each angle according to Equation 2, ......, ,,,,,,,......., and draws vertical luminous intensity distribution profile of fan beam.

### 3.3.2 Measurement of Luminous Intensity Versus Time

(1) Measurement Direction

For pencil beam, the direction of reference axis is taken as the measurement direction; For fan beam, the direction of any  percentile intensity measured in 3.3.1 (3) on the reference plane is taken as the measurement direction. In general, the measurement direction is denoted as (0,0) direction.

Note: the  percentile intensity means that 90% of the measured luminous intensity are higher than this intensity.

(2) Measurement of Luminous Intensity of Steady Light

A conventional photometer is used to measure the luminous intensity in the direction (0,0) mentioned in 3.3.2 (1), and the average value of the three groups of readings is taken as the luminous Intensity of steady light , .

If the AtoN light under measurement is modulated, ensure that the deviation of three readings are within 1%, otherwise a fast photometer is required. A fast photometer is used to measure the luminous intensity profile versus time for 1s in the direction (0,0) described in 3.3.2 (1) to calculate the modulation period of the modulation light, and the average luminous intensity within one or more complete periods is taken as the luminous intensity of steady light ,.

(3) Measurement of Effective Intensity of Rhythmic Light

a. Direct measurement method

With the measurement distance of 3.2.3 (3), the AtoN light is set to the rhythmic light state in the  direction of (0,0) described in 3.3.2 (1). When the stability requirement of 3.2.3 (2) is met, a fast photometer is used to measure the instantaneous intensity versus time profile of each flash individually. The measurement duration shall not be less than one period, and the sampling frequency shall not be less than 500Hz. Then the effective intensity of the specified rhythmic light is calculated according to 3.1.2.

b. Conversion measurement method

The AtoN light is set to the steady light state, and the luminous of steady light is measured three times according to the method of 3.3.2 (2) with the measurement distance of 3.2.3 (3). If the deviation of the three readings is greater than 1%, the measurement should be carried out according to 3.3.2 (3) a.

A fast photometer is used to measure the fixed illuminance  at any position. Then the test AtoN light is set to the rhythm light state. When the stability requirement of 3.2.3 (2) is met, the fast photometer is used to measure the instantaneous illuminance versus time profile of each flash individually at the same position as the measurement of . The measurement duration shall not be less than one period, and the sampling frequency shall not be less than 500Hz. If the modulation light frequency of the AtoN light is higher than 500Hz, the fast photometer shall be set with a higher sampling frequency. Calculate the effective illuminance according to the method described in 3.1.2. The effective intensity, , of the rhythm light in the direction (0,0) is calculated according to Equation 7.

 (7)

Where:

is the effective intensity of the rhythm light in the direction (0,0).

 is the luminous intensity of steady light, which is the average value of three measurements.

 is the illuminance of steady light state at a certain position.

is the effective illuminance in the rhythmic light state at the same position as the measurement of .

c. Estimation measurement method

In some occasions with low requirements, the effective intensity of rhythmic light can be estimated by looking up the table.

The AtoN light is installed in the goniophotometer according to 3.2.3 (1). The luminous intensity of steady light is measured according to 3.3.2 (2). The effective intensity of rhythmic light can be estimated by referring to the method of IALA G1135 Annex B, based on the light waveform and rhythmic character information of the AtoN light.

### 3.3.3 Measurement of Luminous Intensity of Array AtoN Light

For array AtoN lights, the luminous intensity of each area shall be measured according to the method of 3.3.2 (2), and the effective intensity of the rhythmic light of each area shall be measured according to the method of 3.3.2 (3). The sum of the luminous intensity of each area is the luminous intensity of the AtoN lights.

# 4 request

At present, IALA's recommendation on Marine signal light measurement is R0203, which is planned to be developed into a guideline in the next task plan. The details in this input paper are closely related to R0203. We hope the committee will consider China's work on the measurement of luminous intensity of AtoN light. If appropriate, the relevant contents of this input paper can be included in the new guideline developed from R0203.

Appendix

## Appendix A Interpretation of the Text

**1 Spectral Mismatch Correction of the Photometer**

Due to the spectral mismatch correction of the photometer, it has been verified by experiments(Table 1). When measuring monochromatic light, the mismatch of the probe will cause a large measurement error, so the spectral mismatch error must be corrected.

Table 1 Study results of spectral mismatch of fast photometer

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample Number | No.1(green) | No.2(white) | No.3(green) | No.4(red) |
| The mismatch index=5% | 11.3% | 7.4% | 15.2% | 21.3% |
| The mismatch index=7% | 12.5% | 8.2% | 17.0% | 27.9% |

**2 The measurement sensitivity of the photometer**

According to the research on the measurement distance, due to the special lens structure of the AtoN light, the measurement distance is at least 70 times the diameter of the annular luminous surface of the AtoN light. Moreover, the luminous intensity of the AtoN light is relatively weak, so the sensitivity of the equipment is required to be high. The AtoN light with effective intensity of 1cd can meet the range of 1.0 nautical miles. If measured in the laboratory, when the measurement distance is 10m, the corresponding illuminance value is only 0.01lx. Therefore, it is specified that the measurement sensitivity of the photometer shall be better than 0.001lx.

**3 LED Light Modulated by PWM**

LED are widely used in AtoN lights. Some LEDs are PWM modulated. When measuring this kind of modulated light, if the modulated light frequency is below the lower limit or above the upper limit of the frequency of the conventional photometer, or the peak is overloaded, or the setting time is not completed, the photometer reading will deviate from the arithmetic mean. Therefore, the modulation light performance of conventional photometer is required in the text.

**4 Sampling Frequency of Fast Photometer**

Two groups of ryhthmic characters of AtoN light were selected for testing:

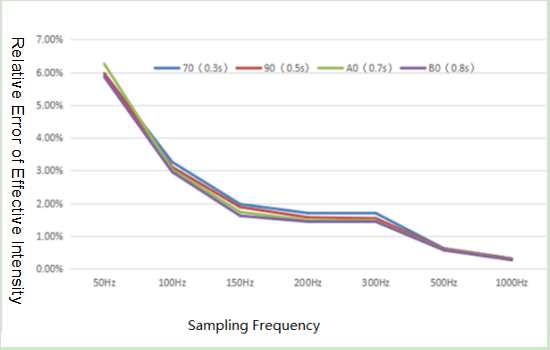
The first group with the same frequency and different flash duration.

1. f(0.5Hz), on(0.3s), off(1.7s);
2. f(0.5Hz), on(0.5s), off(1.5s);
3. f(0.5Hz), on(0.7s), off(1.3s);
4. f(0.5Hz), on(0.8s), off(1.2s).

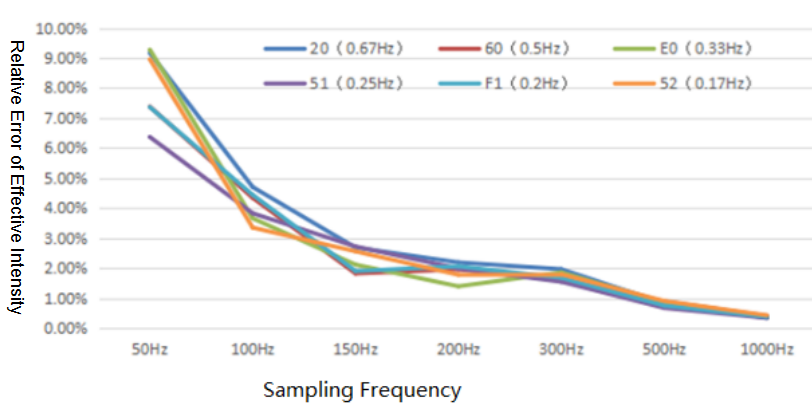
The second group with the same flash duration and different frequency.

1. f(2/3Hz), on(0.2s), off(1.3s);
2. f(0.5Hz), on(0.2s), off(1.8s);
3. f(1/3Hz), on(0.2s), off(2.8s);
4. f(0.25Hz), on(0.2s), off(3.8s);
5. f(0.2Hz), on(0.2s), off(4.8s);
6. f(1/6Hz), on(0.2s), off(5.8s);

The effective intensity of each character is measured at sampling frequencies of 50Hz, 100Hz, 150Hz, 200 Hz, 300 Hz, 500 Hz, 1000 Hz and 20,000 Hz respectively. Then the error of each effective intensity relative to the effective intensity at 20000 Hz is calculated.



*Figure A.1 Research results of sampling frequency (the same frequency, different duration)*



*Figure A.2 Research results of sampling frequency (the same duration, different frequency)*

The two groups of datas show the same results, that is, the relative error decreases gradually with the increase of sampling frequency, and when the sampling frequency reaches 500Hz, the relative error of effective intensity is less than 1%. Therefore, in the text, the sampling frequency is specified as at least 500Hz.

The sampling frequency shall be at least 500Hz, but if there is PWM modulation, and the modulation frequency is usually hundreds of Hz, in order to meet the sampling law, the sampling frequency of the fast photometer shall be at least 1kHz and the response time shall not be greater than 10μs。

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Input papers should be assigned to a work task as listed in the Committee work plan which is available in input papers. Leave open if uncertain but consider how the paper is to be processed if not relevant to a work task [↑](#footnote-ref-2)