Paper 120 - Modern LED Light Solutions for Safe Navigation on Inland Waterways

RAINER STRENGE;
Traffic Technologies Centre, Federal Waterways and Shipping Administration of Germany, Koblenz, Germany

Email (1st author): rainer.strenge@wsv.bund.de

ABSTRACT: Despite the growing use of modern technical systems, i.e. AIS, Inland ECDIS with satellite navigation (GNSS) and radar etc. visual aids to navigation (AtoN) are still further important for ensuring a save navigation. For some years lamps with LED (Light Emitting Diode) light sources have shown rapid developments in providing high light intensity and energy efficient light solutions. Traffic Technologies Centre of the German Federal Waterways Administration has developed technical standards for LED applications used at fixed and floating AtoNs. The paper will introduce examples.

1 INTRODUCTION

LEDs (Light Emitting Diodes) are part of signal and lighting technology these days. The German Federal Waterways and Shipping Administration (WSV) started the introduction of LED lights for Aids to Navigations (AtoN) on inland waterways a decade ago. These developments mainly involved adapted technical solutions originating in coastal use. However, there are still a lot of lights and signal systems using incandescent or discharge lamps on the German inland waterways. Some panel signs are still illuminated by propane gas powered lighting in locations that have no access to the electricity grid. The Federal Ministry of Transport and Digital Infrastructure (BMVI) decision to make comprehensive use of LED technology led to the development of standard technical solutions to a variety of needs. Examples of LED applications with regard to light specifications are presented in the text that follows for:

- Fairway buoys;
- Sector lights;
- Waterway panel signs;
- Signal rafts;
- Lock signals;
- A new concept of entrance marks at locks.

2 LED AND VISUAL AIDS TO NAVIGATION

2.1 *LED*

A LED is an electronic semiconducting component. By contrast with a light bulb it needs a complex electronic power source. The light emitted by a LED is nearly monochrome compared to an incandescent or fluorescent lamp. LEDs can emit light in red, green, yellow and blue depending on the crystals used. White light is generated with the aid of an additional yellowish luminescent coating or by colour mixing. Efficiency is measured in lumen per watt (lm/W). White LEDs nowadays can achieve more than 100 lm/W for practical use. The theoretical limit is about 300 lm/W.

LEDs are subject to ageing, caused mainly by heating of the semiconductor material. This is regardless of temperature rise being due to electrical energy or e.g. sun light that heat the housing in the daytime. Degradation of light intensity can be compensated by adjustment if the LED isn't operated at its maximum capacity from new. Light intensity adjustment in signal systems is often by fast on/off switching (Pulse Width Modulation).

In light bulbs a defect can be detected by simply monitoring electrical current. This is very complex with LEDs. However, faults are often due to malfunctions in the control electronic components rather than LED failure. One disadvantage of LED lamps is that the entire light often needs replacing and proper disposal if it fails.

2.2 *Relevant standards for AtoN lights*

The general framework for visual Aton's is laid down in the UN ECE Resolution No. 59 "Guideline for Waterway Signs and Marking" and the UN ECE Resolution No. 22 "SIGNI - Signs and Signals on Inland Waterways". International and national traffic regulations such as the River Rhine Shipping Police Ordinance of the Central Commission for Navigation on the Rhine (CCNR) also include general descriptions of AtoNs.

More technical information is given in the recommendations of IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities). However, supplementary information is often needed on light engineering specifications. Road traffic signage rules have proven useful. The LED applications described later in this document are in accordance with:

- IALA Recommendation E-200 On Marine Signal Lights (Parts 1 to 4);
- European Standard EN 12899 – 1:2007 (Fixed, vertical road traffic signs).

Other guidelines and specifications must of course be observed in the technical realisation of light signal systems, including those concerning designing means of setting such systems up, electromagnetic compatibility and safety aspects.

2.3 *Light engineering specifications*

2.3.1 Lights

The photometric luminous intensity in candela is used to technically specify a navigational lantern. Photometric luminous intensity is the currently quantifiable light intensity of a light. For luminous range calculation the effective light intensity is used. This factor takes into account visual weakening caused by flashing or operating factors that reduce the intensity, such as dirt or degradation. The luminous range of a signal light is determined using the IALA1-Rec. E-200, Part 2 - Calculation, Definition and Notation of Luminous Range procedure. This only applies to signal lights the observer sees in point form. For the design of a signal light the meteorological visibility and background illuminance is of importance. Examples are given in figure 1.

Background illumination	None	Moderate	Considerable
Required illuminous intensity at the eye of the observer, E_t [lx]	$E_t = 2*10^{-7}$ lx For lighted buoys and fixed lights without background light	$E_t = 2*10^{-6}$ lx For all lights with moderate background illumination, city	$E_t = 2*10^{-5}$ lx For all lights with considerable background illumination, industrial area
Effective light intensity [cd]	**Luminous range [m]**		
1	1 760	650	220
2	2 300	890	300
5	3 210	1 320	470
10	4 050	1 760	650
20	5 010	2 300	890

Figure 1: Luminous ranges for a given meteorological visibility of 11 km

The design of a signal includes the required light distribution in horizontal and vertical directions. A vertical light distribution for specifying omnidirectional light of a buoy lantern is given in figure 2.

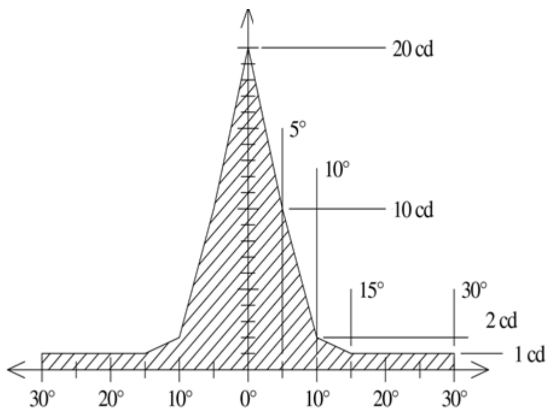

Figure 2: Vertical light distribution of a buoy lantern (the graph defines min. values of light intensity)

In addition maximum intensity must be defined in order to avoid glare. The half-peak divergence angle is of practical value and is defined as the angle at which the luminous intensity equals half of its maximum value. Isocandela graphs (a line joining points that have the same luminous intensity) are another way of specifying two-dimensional not symmetrical complex light distributions, e.g. in specifying signal lanterns for use at locks.

Permissible light colours are specified in ranges (x-, y coordinates) within the standard colour triangle per ISO 11664 / CIE S 014. Figure 3 indicates the chromaticity range specified for white, yellow, red and green according to IALA Rec. E 200- 1.

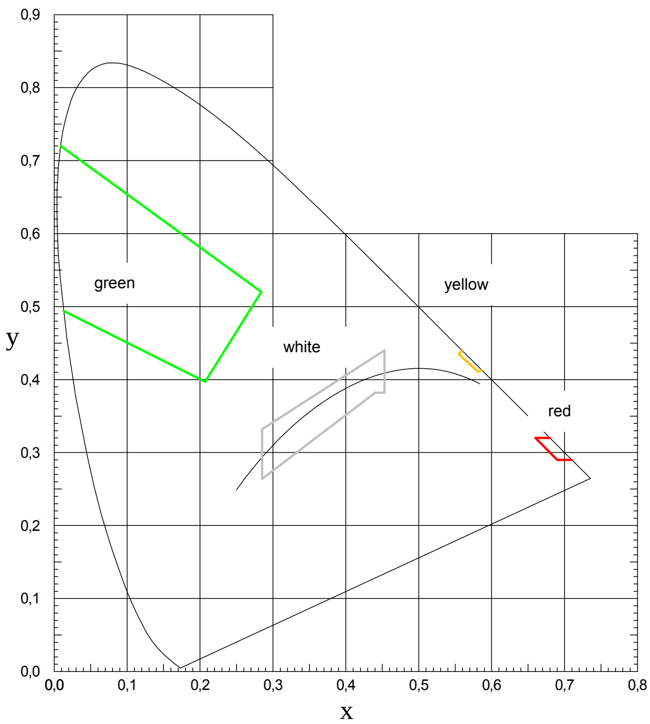

Figure 3: IALA allowed chromaticity areas for red, green and white colours

2.3.2 Illuminated signs

The perceptible brightness of a self-illuminated waterway sign is quantified by its luminance (brilliance). If the sign is lighted by a lamp then illuminance measured in lux is used. The required brightness a panel sign needs depends on ambient brightness and the intensity of competing lights. For this reason EN 12899 includes brightness classes. The Illumination should be uniform in order to avoid that parts of the sign may be invisible, figure 4. Uniformity is defined as the ratio of the lowest to the highest measured luminance/Illuminance.

Figure 4: examples of waterway signs showing low uniformity of illumination

To ensure that the colours of the signs are not falsified by the illumination, the required colour temperature of the LEDs should be approx. 4000 K (neutral white).

3 LED APPLICATIONS

3.1 *Fairway buoys*

Fairway buoys are good detectible by ships radar. Light buoys are hence only to be found on the 7.350 km German inland waterways where they're really needed. There are only about 60 lighted buoys.

One project deals with the mountainous Rhine (Loreley rock) with high demands on navigation due to strong currents and narrow channels. There was a need to mark the bifurcation at the Geisenruecken fairway and other parts of the navigable channel with lighted buoys. The standard oval polyethylene plastic buoys that have proven themselves in the strong currents here are to be modified so that solar LED systems can be installed on them, figure 5.

Specifications for a lantern with solar power and batteries were developed based on the IALA Guideline No. 1064 "On Integrated Power Systems Lanterns (Solar LED Lanterns". The system allows 20 days operation without charging by sunlight.

A luminous range of 3,000 m is adequate in view of the geographical conditions and to avoid glare. The photometric light intensity for red and green lanterns is 10 cd (iso phase light) and 20 cd (continuous light) for white used to mark the channel split. The half peak divergence angle is 10 degrees so that buoys tilted by the current are still easily identifiable.

Figure 5: Standard PE oval buoy with lantern, solar power box and integrated radar reflector, positioning of the 335 kg buoy

The Lanterns are automatically activated by an astronomical clock or dimmer switch. The lanterns can be remotely controlled for testing purposes and for monitoring to record operating data such as the battery charge status. Buoy position is automatically determined and recorded by GPS sensor. If a buoy leaves its position an alarm is generated and transmitted via SMS. The extent to which the sensor system could be expanded to detect and notify collisions is currently being tested. This is of particular importance here due to buoys often being overrun by ships. With regard to work safety aspects the safe handling when placing and removing the buoys is an important requirement.

3.2 *Sector lights*

Sector lights are rarely in use on inland waterway. A sector light is a fixed installation that shows strictly limited horizontal angle light beams to guide shipping in a safe channel. Sector lights have been in use for years on lakes near Berlin. Red, green and white LEDs provide the light for marking the sectors. Figure 6 shows the Schmoeckwitz light that is now equipped with a LED standard device available on the market. The photometric light intensity and sector angles were specified. Sector angles were set in the laboratory. There are adjustment means on the masts to make installation easy and safe. The system includes a photo voltaic energy supply.

Figure 6: LED Sector light with photo voltaic system mounted on a mast, nautical range: 1700 m, sector angles: 1°- 5°

3.3 *Waterway panel signs*

Panel signs on inland waterways are for traffic regulation, information and warnings to shipping. Important ones are illuminated at night.

3.3.1 *Illuminated waterway panel signs*

For many years the illumination was electrically powered by 36-40 W fluorescent lamps where electricity was available or for temporary use, e.g. marking of construction areas. The panels were illuminated using propane gas driven lamps. 500 of such signs are currently in use. However, the industry does not support this technology anymore and spare parts are no longer available for them. Work safety standards for propane gas equipment are rigorous and require regular training and refresher courses. Switching to LED and photo voltaic power supply will reduce maintenance and repair costs.

In the course of developing the requirements for a standard LED lamp the relevant light designing parameters were determined in laboratory tests. The illumination requirements were than specified according to EN 12899. Two intensity classes depending on energy supply and background light level have been laid down.

A European wide call for tender led to the product that is shown in figure 7.

Figure 7: Illumination of a panel sign with LED lantern, right picture: LED light compared with fluorescent lamp

The chosen LED lantern is robust and lightweight. A good combination of LEDs and lenses enables a bright and even uniform illumination of large panel signs. The lantern is specified to have a guaranteed service life time of at least ten years. During this period illumination should remain even, colour temperature remains in the permissible range and the illuminance not be less than 70% of the specified value. Technical data are listed in figure 8.

Standard LED lantern			
Voltage	230 V AC	12 V DC	12 V DC
Power	20 W	6 W	10 W
Luminous flux	1250 lm	450 lm	650 lm
Colour temperature	Neutral white	Neutral white	Neutral white
Connection to electricity net	yes	No	No
Remark	Standard	Standard	high Background illumination

Figure 8: Technical data of standard LED lantern

The lanterns are usually mounted on a panel sign extension. For large panels two lanterns can be used. Figure 9 shows the mechanical construction for a mobile system used for temporary marking and a stationary system.

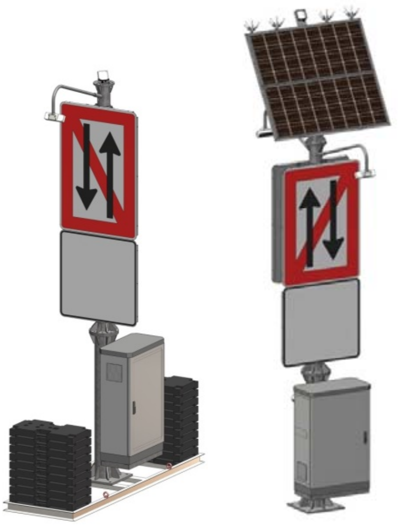

Figure 9: Mobile (left picture) and stationary panel sign systems

Energy supply is based on solar power with lead gel storage batteries. Mobile systems for temporary marking have no solar panels. Sets of lead gel storage batteries supply the energy needed and are replaced when drained. Tests of lithium-ion rechargeable batteries are currently being held; they are lighter and have higher storage capacity but charging them is more complex technically. Fuel cells have also shown up well in trials. Their use has, however, been postponed for work safety reasons.

3.3.2 *Waterway panel signs with internal illumination*

At some bridge building sites panel signs with internal illumination are used to avoid disrupting the architectural appearance, Figure 10.

Figure 10: Available internal lighted panel sign

There are two different technical types of internally lit panel signs available:

a) Full back lighting with white LEDs, the colour of the backlit surface is entirely due at night to the colouring of panel sign foil;

b) Back lighting coloured surface elements with LEDs of the same light colour.

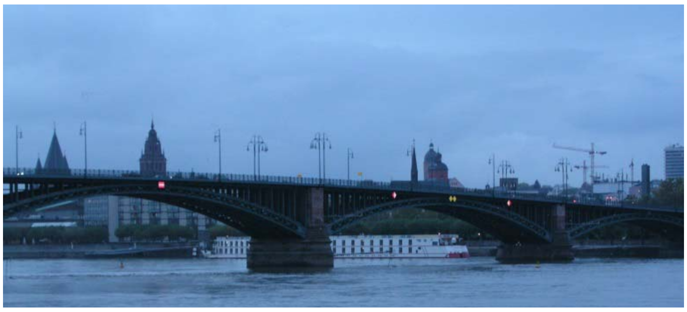

Figure 11: Internal lighted panels at Rhine Bridge

Back lighting makes outstandingly good visual characteristics that yield high visibility at long ranges, Figure 10. The arrangement of the LEDs must suit the panel signs concerned; every picture thus needs its own design. The lights specification is in accordance with EN 12899, Figure 12.

Light design for internal lighted panels		
colour	**L_{mittel} [cd/m^2]**	**uniformity**
white	120	≥ 1/3
yellow	60	≥ 1/3
red	60	≥ 1/3

Figure 12: Photometric specification of internal lighted panels

High costs are a disadvantage in both types. The entire panel sign has to be replaced if there's a defect. Experiences show a service life time of about 5 years.

3.4 *Signal rafts*

Signal rafts temporarily mark danger points and obstructions on inland waterways. With the exemption of some prototypes the signals currently use lanterns and panel signs that employ propane gas as power source. In connection with the conversion of 60 rafts with regard to better operation and work safety LED-lanterns with photovoltaic power systems are envisaged. In addition four new rafts for improved transport with push boats with larger dimensions are currently built for the Rhine River, Figure 13.

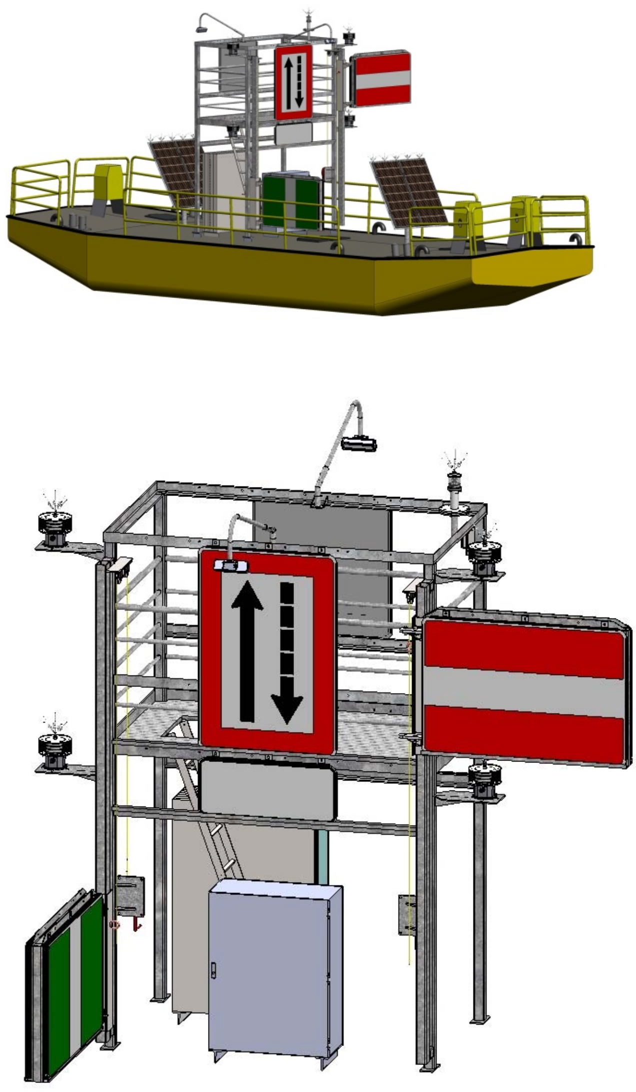

Figure 13: New raft (13 m x 4 m) with signal mast and store for batteries and panel signs

The signal lanterns are aligned along the fairway. Three colours (red, green and white) can be shown for the defined directions 0° and 180° by each lantern. A total of four lanterns will be used per signal raft (two levels each side), Figure 14, 15.

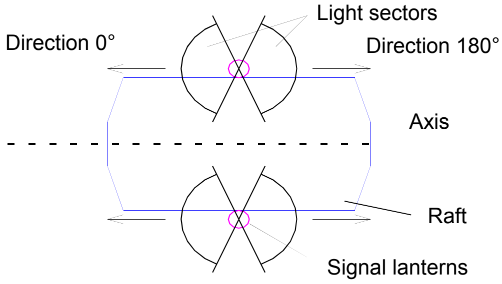

Figure 14: Light sectors (view from above)

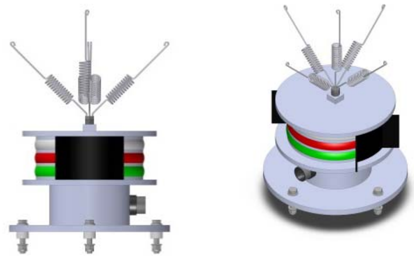

Figure 15: Raft signal lanterns with 6 lights, 3 colours

Each partial light can be controlled individually, but only one light (colour) is activated per direction. The maximum photometric light intensity is 40 cd for the red and green light colours and 80 cd for white light.

The Illumination of the panel sign in the middle of signal masts is by standard LED-lantern as used for fixed and mobile panel signs described in chapter 3.3.1. The panels displayed laterally on starboard and port side of the signal mast only serve as day mark and are hence not illuminated.

Operation of the lanterns and Illumination is done automatically by astronomical clock or dimmer switches. The signal system can be remotely controlled for testing purposes and for monitoring to record operating data such as the battery charge status.

Fuel cells can be used as an alternative to lead gel storage batteries. Electrical and mechanical interfaces for same have been prepared. Installing water current energy generators was also considered as a supplement to photo voltaic systems. However, on a number of locations along the banks current was not constant and the generator propellers were often damaged by flotsam and hence unusable.

Locked steel cabinets with adequate ventilation are installed on the rafts to store four signal panels. They are so sited that the lifting device on the signal platform can be used easily and safely. Another steel cabinet for photo voltaic system storage accumulators is also installed on board.

3.5 *LED signals at locks*

Light signal systems at locks using incandescent lamps with long service intervals (2000 h) are in general use today, Figure 16. For the conversion to LED-Technology a module was designed to replace the bulbs in order to make further use of the mechanical/electrical interfaces and existing housings.

Figure 16: Lock entrance signals

Optical failure detection was considered. However, a reliably failure detection was not possible. Sunlight reflected from the water’s surface into the lens influenced the sensor and caused this behavior. Also marketable products have still shown this limitation. Therefore, a long service life time of five years was specified. Figure 17 shows a standard LED module that can easily be replaced. The module is designed for lock entrance and exit signals. To integrate the modules in existing control systems an interface is provided.

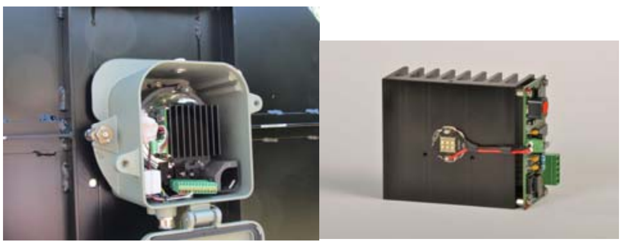

Figure 17: Standard lock signal with LED module

Dispersion plates (Figure 18) ensure the horizontal and vertical light distribution required for most approaches to locks with berths and waiting areas. The luminous light intensity for entrance signals may not exceed the upper limit of 6000 cd in white or 3000 cd in green or red at day time. Saturation of red and green light makes the colours appear stronger than white of the same brightness. White light is therefore used appropriately brighter to harmonize the visual impression of signal signs consisting of white and coloured light.

The same light module is used with reduced light intensity for exit signage at locks and signal light for small locks used by sports and recreational shipping, Figure 18. To prevent dazzle and harmonize with entry signals the maximum radiated light intensity may not exceed 400 cd. Only red and green light colours are specified. The design is according to EN 12368.

Figure 18: Exit signal and dispersion plates

To prevent dazzle light intensity is cut to 20%, or alternatively in two stage night mode switching to 30% and 10% of the light intensity in daytime for both signal types. Switching can be by measuring the ambient brightness (horizontal illuminance). Alternatively brightness of the signals can be switched manually or by clocks.

3.6 *New concept of lock entrance marks*

Visual aids to support entering locks include daylight marks and illuminated marks for night-time use. A guideline introduce in 1976 still applies to the specifications of same. An investigation confirmed that there is a need for improvement of the existing navigational aids with regard to visual conspicuity. A technical solution for daytime and night-time marking was drafted based on theoretical considerations and visual evaluation of test structures at the Koblenz lock, Figure 19.

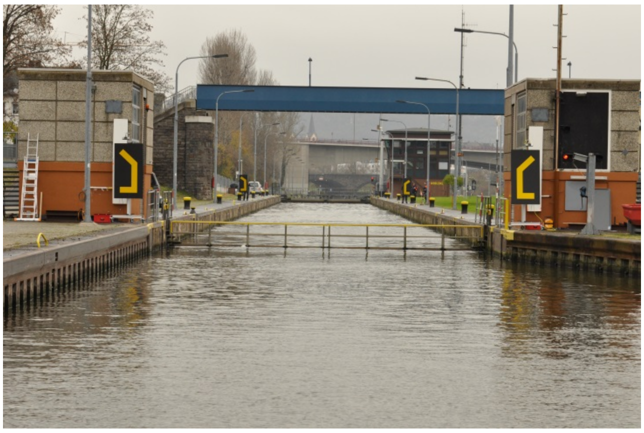

Figure 19: Test marks at Koblenz lock

Figure 20 indicates the signs for marking the lock chamber sides and if necessary the axis. The special form was chosen to ensure a good conspicuity. The technology employed is based on panels with internal illumination. This has proven itself by marking wind turbines in offshore wind farms.

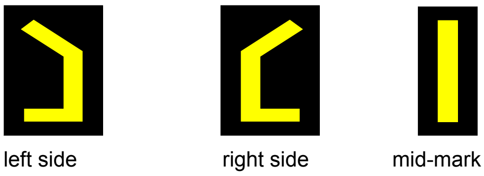

Figure 20: New lock entrance marks

The LEDs are maintained in the frame of the panels and transmit light through a special lens that diverts the beam to an angle of 90 degrees to illuminate the panel surface. This yields compact design with uniform illumination. Light engineering design parameters:

- Daytime marking: yellow (RAL 1023), black (RAL 9005);
- Night time marking: yellow light colour, 30 cd/m $\leq L_{average} \leq$ 100 cd/m², $L_{min} : L_{max} \geq 1 : 3$.

Yellow illuminated surfaces are better visible than white, if the lock is illuminated with white light. However, yellow light from sodium vapour lamps is still currently the standard for illuminating lock areas. Conversion to white LED light is envisaged. Two signal panel sizes will be used. For lock chamber lengths over 100 m the larger one of 1,000 mm x 1,920 mm will be used.

The principle concept is based on marking the chamber sides near to the upper and lower gate. The "double door" panels appear not to be symmetrical when viewed other than on the lock axis, Figure 21. Eight panels (4 each way) must be installed per lock chamber, Figure 22.

If the lock design makes double door marks invisible at nautically relevant distances, e.g. at high locks or locks at which signal panels are obscured by the lock structure, a mid-mark should be used.

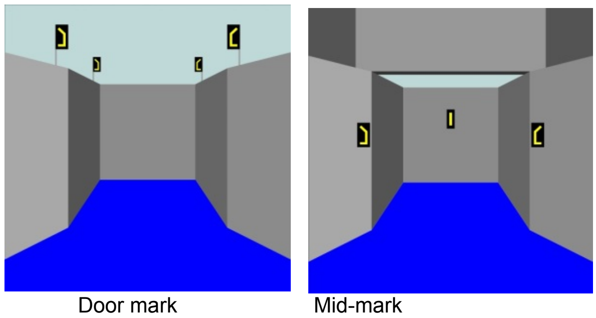

Figure 21: Principle of entrance marks

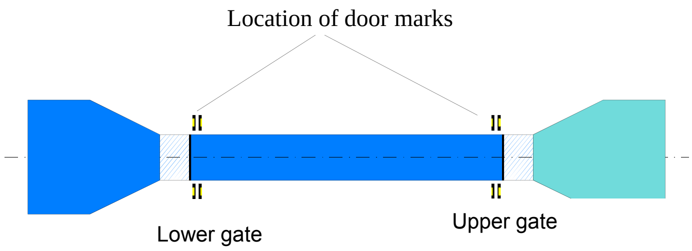

Figure 22: Location of door marks

The concept is currently being tested at selected locks. In addition the ship simulator of BAW, Federal Waterways Research Institute is being used for further assessments. A formal introduction by the end of 2015 is now envisaged after evaluation of the trials.

4 SUMMARY

Despite the growing use of modern technical systems, i.e. AIS, Inland ECDIS with satellite navigation (GNSS) and radar etc. visual aids to navigation (AtoN) are still further important for ensuring a save navigation. With the use of LED Technology the performance of visual AtoNs can be improved. A key element of ensuring a good performance is to have appropriate specifications and standards that must consider the benefits and the limitations of this technology. However, standards need to be adapted with regard to current trends and developments, e.g. bigger and faster ships, light pollution effects and progress in light technology. LED lights were successfully introduced for fixed and floating AtoNs on inland waterways. However, there is a potential for improvements.

REFERENCES

Technical Standards of Traffic Technologies Centre (Fachstelle der WSV für Verkehrstechniken)

- L13 Illumination of panel signs
- L12 Lights on buoys
- L07 Fixed signal lights
- Entrance marks at locks (draft, 2015)