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Shining a Light on LEDs
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KONGSBERG

SUT Society for Underwater Technology

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There has been a rapid growth of interest in the use of solid-state LED lighting for underwater inspection and survey tasks over the last few years. This has led to a scramble by many underwater lighting manufacturers to introduce new products that take advantage of the latest advances in LED lighting technology.

For the offshore operating companies and scientific organisations that rely on high-power underwater lighting systems for their critical underwater inspection and survey tasks, the promise of a 'fit and forget', high reliability solid-state LED lamp with claims of 50 000 hours operating life must seem very seductive.

This article aims to shed some light on modern high-power LED lighting technology and to explore some of the performance issues that need to be considered by users when deploying LED lighting systems for underwater inspection and survey tasks.

What's so great about solid-state LED lighting anyway?

For decades now, the most common artificial lighting technology used for illuminating underwater inspection and survey tasks has been the humble incandescent bulb. Any new lighting technology being considered for underwater use must be measured against this proven technology.

Halogen incandescent bulbs have been used successfully underwater for very many years, and their performance limitations are well known:

Halogen incandescent lighting: Performance limitations

- **Limited operating life.** Typically 100-2000hrs bulb life
- **Heat generation.** Using them for any extended periods in air can lead to heat damage to underwater pressure seals and lamp integrity
- **Relatively inefficient.** They have lower light output per Watt of power input than a typical fluorescent lamp or high-intensity discharge lamps
- **Not very robust.** Light is produced by a thin, glowing 'white-hot' metal filament that can be prone to sudden shock and vibration failure.

Set against this, halogen lighting does have some inherent advantages which operators and users now take very much for granted:

Halogen incandescent lighting: Performance advantages

- Consistent correlated colour temperature (CCT) or around 3200K
- Excellent colour rendering performance. It produces the full range of visible light wavelengths suitable for critical colour inspection tasks
- Wide range of voltage and power options available
- Consistent lighting performance over the full bulb operating life
- Light output not affected by changes in operating temperature

Using halogen lighting as our performance benchmark, how does the latest generation of high-output underwater LED lighting perform? The claimed advantages for this rapidly developing technology are impressive:

Solid-state LED lighting: Claimed performance advantages

- High-reliability solid-state technology
- Greater luminous efficacy. Producing a greater light output for the same power input when compared with halogen incandescent lights
- Produce less radiated heat than halogen lights
- Very long operating life, typically quoted as between 25 000 and 50 000 hrs for many LED lamps. This is between 10 and 20 times longer than for halogen
- Resistant to high shock and vibration, as there is no glowing filament to break!
- Suitable for very fast switching and high ON/OFF duty cycles. LED light reaches a maximum brightness within microseconds of switch-on and does not suffer damage from repeated on/off switching.

The lure of an efficient, highly reliable, rugged, solid-state LED lamp unit with a very long operating life should indeed be of great interest for underwater inspection and survey tasks.

So where is the catch with LED underwater lighting?

The many advantages of using LED lighting for underwater inspection tasks seem like a very compelling argument for the rapid adoption of this new technology, even when weighed against the fact that the initial procurement price for underwater LED lighting is significantly greater than for the traditional halogen lamps.

But if we dig a little deeper into the performance of these LED devices we see that there are still some fundamental performance limitations which might affect our decision.

Light on LEDs

ave Mackay, General Manager, Kongsberg Maritime Limited

Solid-state LED lighting: Performance limitations and issues

- **Poorer colour rendering performance.** LED lights tend to have a more restricted range of visible light wavelengths compared with halogen lights, especially at red wavelengths of light which are heavily absorbed by water

- **Inconsistent correlated colour temperature.** There are a wide range of CCTV options for 'white' LEDs ranging from 3000-7000K, making it difficult to match them with underwater TV camera colour balance settings

- **Inconsistent luminous efficacy.** LED lights with the higher luminous efficacy also tend to have the poorest colour rendering performance, making them much less suitable for critical colour inspection tasks

- **Light output affected by operating temperature.** LED lamps become less efficient as internal temperature increases; temperature control is a major design issue for high power underwater LED lamps.

- **Reliability can be affected by LED internal temperature.** Contrary to popular wisdom, high-output LEDs can be subject to sudden, unexpected failure or much reduced operating life if the internal lamp temperature is not adequately controlled

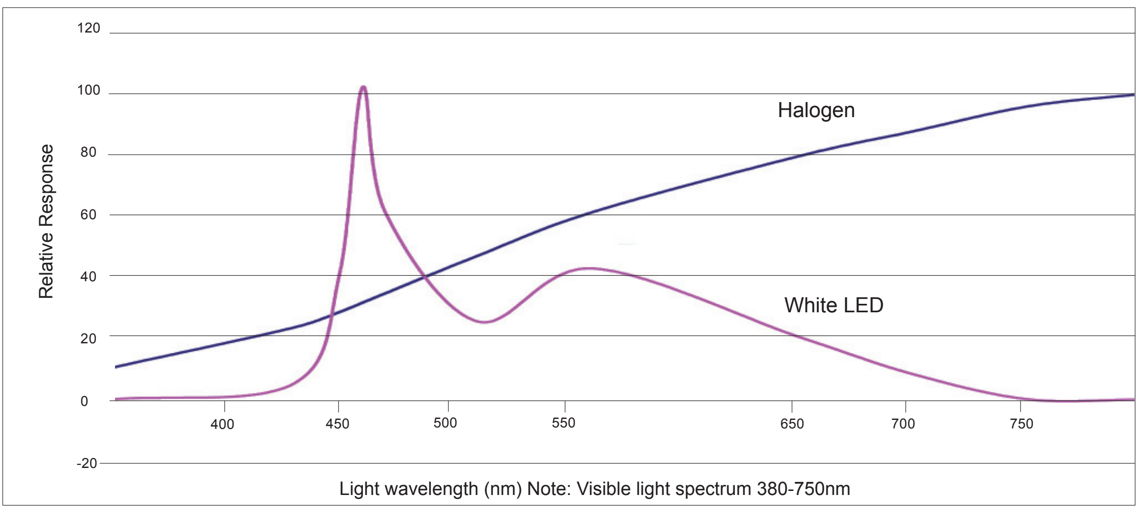
- **Potential 'blue/UV' eye safety hazard.** The latest high output 'white' LEDs tend to have a very intense blue or UV light output, often exceeding current eye-safety viewing limit guidelines.

Looking at some of these performance issues in a bit more detail, let's start with the issue of colour rendering performance.

Why is it so important?

Critical underwater inspection tasks often rely on the viewer (or the underwater TV camera) capturing a full range of colours and then being able to display them accurately on screen. This can often be critical for proper damage assessment, corrosion monitoring, monitoring of marine fouling build-up or for marine species identification.

The problem with typical 'white' LED lamps is that there are no natural white, high-efficiency, high-output LEDs. Most high-power, white LEDs are actually high-efficiency blue (or ultraviolet) LEDs which have been modified with an internal yellow phosphor coating to fill in some of the missing colours of the spectrum.



The graph shows a comparison between the relative visible light spectral response of a typical White LED lamp compared to that of a Halogen Incandescent lamp. Note that the White LED has a restricted light spectrum coverage compared to halogen, with a big spike in the blue region, and a smaller peak in the yellow-green region. There is very little response at the red end of the light spectrum (650nm and above).

Shining a Light on LEDs

These phosphor-based white LEDs give the appearance of producing white light. In practice, however, they produce a more limited range of light wavelengths than is present in natural daylight, or in incandescent halogen lamps. This makes typical high-output white LED lamps much less suitable for critical colour inspection and survey tasks, despite the bold claims of some unrealistic specification sheets.

The issue of luminous efficacy also has an impact on the colour rendering of an LED lamp. It is possible to improve the colour rendering performance of a phosphor-based white LED by adopting more complex phosphor configurations, but the downside of this approach is that it reduces the luminous output from the LED and increases the thermal heat build-up in the device. This is often bad news for life expectancy and reliability.

There is a trade-off in performance between accurate colour rendering, luminous efficacy and thermal heat build-up. LED lighting units with better colour rendering performance tend to have lower luminous efficacy - sometimes little better than halogen lighting units - and need much greater care in designing thermal control mechanisms to prevent long-term reliability issues.

Inconsistent colour temperature (quoted as CCT), is also a serious consideration for professional users who need consistent colour inspection quality underwater. Halogen lighting always has a consistent CCT of around 3000-3200K.

The majority of underwater colour inspection TV cameras in use around the world today are specifically designed to operate with this fixed colour temperature.

For high output white LED lighting there is no consistent colour temperature. It can typically vary between 3000K-7000K depending on the design decisions made by the lamp manufacturer and the compromises they have decided to make regarding luminous efficacy and colour rendering. This can make it very difficult for operators to achieve consistent colour inspection quality from LED lamp installations.

CRI

The colour rendering performance of a lamp is often measured using the colour rendering index (CRI). This index measures the deviation in light spectrum output compared to an ‘ideal' black-body radiator.

Typical halogen lamps have a CRI measurement close to the ideal of 100. Typical white LED lamps have a CRI score of between 60 and 70 (the higher the better)

The higher the LED light output (higher luminous efficacy), then the higher the colour temperature and the poorer the expected colour rendering performance. Colour rendering performance can also be affected by lamp operating conditions.

Let's Now Turn to Long-Term Reliability

Are the typical claims of 50 000 hours operating life realistic for underwater LED lamp units?

Unlike halogen lighting, the performance of LED's does degrade throughout their operating life, and they gradually become less efficient and grow dimmer with age. So although there may be no glowing filament bulb to fail, the performance does tend to deteriorate over time.

The other major factor affecting the longer-term reliability of LED lamps is internal temperature. Controlling the internal temperature of a high-output LED lamp is critical, both to ensure consistent colour performance and luminous efficacy and to maintaining long-term reliability.

It is often said among underwater equipment designers that the sea is a wonderful heat-sink. This does not mean that the issue of temperature control is trivial for underwater LED lamp designers.

Thermal design is a critical aspect of LED lamp design, especially within the sealed and tightly packed waterproof enclosure of an underwater lamp. Some designers adopt ‘automated' temperature limiting circuitry within their lamps to prevent localised LED over-heating and reliability problems. The downside of this approach is that the light output and the colour quality performance can vary significantly with changes in temperature.

There seems to be little doubt that LED lighting for underwater use is here to stay and that it has a very bright future, but care must be taken when assessing the suitability of LED lighting for critical colour inspection and survey tasks. Inconsistent performance and poorer colour rendering may mean that LED lighting is not always the best choice.

Kongsberg's LEDs

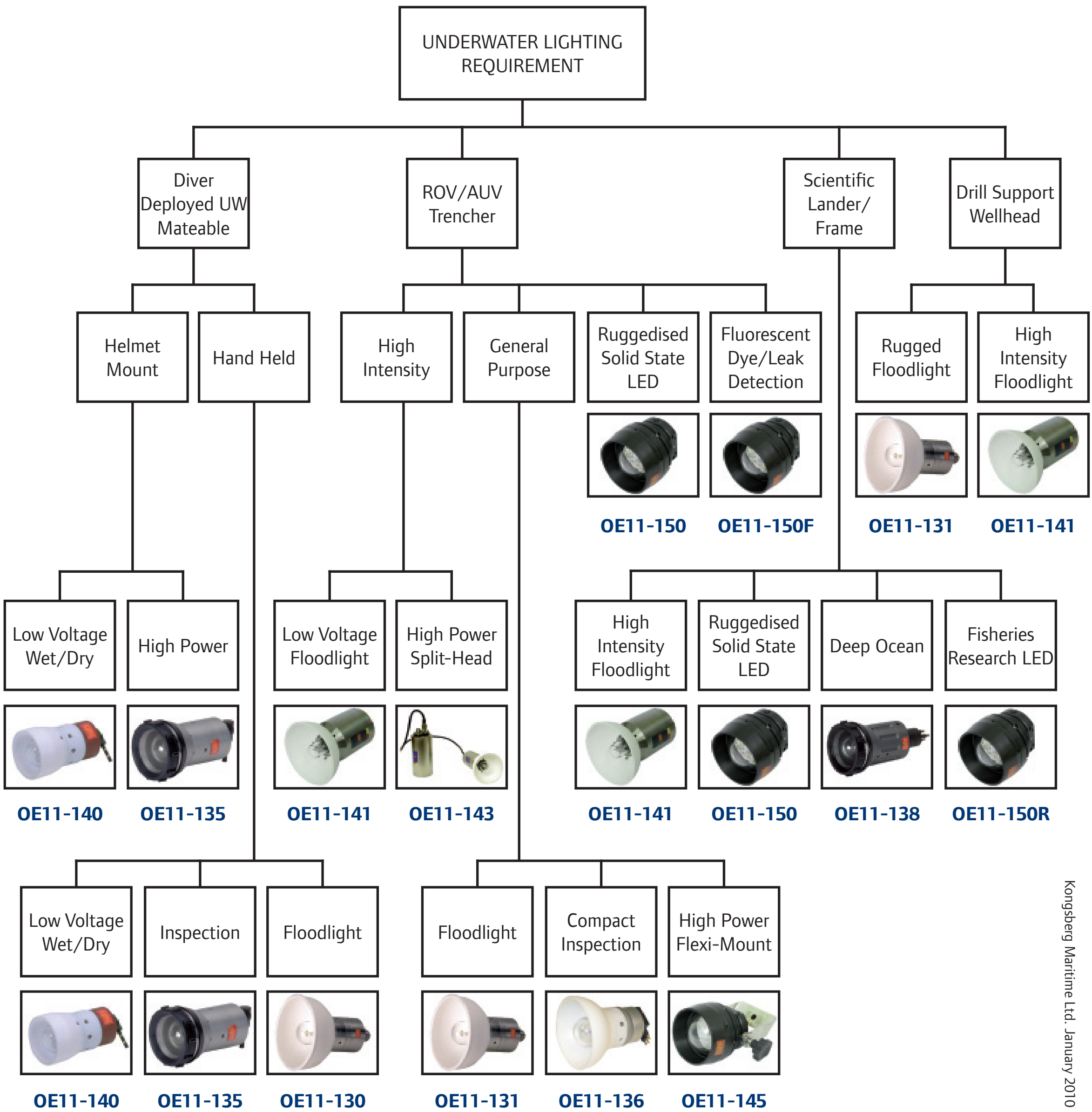
Kongsberg Maritime offers a robust general-purpose white LED lamp for underwater ROV inspection (the model OE11-150). The lamp has a total luminous output of 2460 Lumens, providing an illumination of 800 Lux at a distance of 1m in water.

The lamp has a correlated colour temperature of 4100K (optional 3200K or 6500K), with a colour rendering index of 70. The lamp has a uniform beam angle of 68deg in water. The lamp is available with either DC or AC power input options.

Kongsberg also offers a version of the lamp for fluorescent dye leak detection (the OE11-150-F) and another version for fisheries research (the OE11-150-R).

Kongsberg's Underwater Lighting Product Application Guide

Kongsberg offers a comprehensive range of robust underwater lamps, floodlights and flashguns:



Kongsberg Maritime Ltd. January 2010

Model	Lamp Type	Bulb Type	Luminous Output (lm)	Illumination @ 1m (Lux)	Power Input (W)	Colour Temp (K)	Colour Quality (CRI)	Beam Angle ° (-3dB)
OE11-130	General Purpose (GP) Floodlight	Halogen	5000	1300	250	3200	100	100
OE11-131	GP Floodlight	Halogen	5000	1300	250	3200	100	100
OE11-135	Miniature GP Inspection Lamp	Halogen	4650	550	300	3200	100	70
OE11-136	Miniature GP Flood Lamp	Halogen	4650	1100	300	3200	100	>80
OE11-138	Deep Water GP Lamp	Halogen	4650	550	300	3200	100	70
OE11-140	Wet/Dry GP Inspection Lamp	Halogen	1500	175	75	3200	100	100
OE11-141	High Intensity Floodlight	Metal Halide HID	4500	1600	60	4200	98	100
OE11-143	High Intensity Floodlight	Metal Halide HID	21200	5600	300	3200	90	100
OE11-145	GP ROV Inspection Lamp	Halogen	4500	2400	250	3000	100	72
OE11-150	GP Solid State Inspection Lamp	LED	2460	800	50	4100	70	68

Please see www.km.kongsberg.com/cameras for full product details, including voltage, bulb, housing and connector options.

Kongsberg offers a comprehensive range of underwater lamps, floodlights and flashguns utilising high performance halogen, HID and LED bulb technologies. Please contact us for further details:

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