Qualification, specification and standardization of UV-LED-Sources for fluorescent magnetic particle and penetrant inspection

Relevant practical basics and backgrounds

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Manufacturer of:
High quality, standard and customized UV-A-LED-sources developed by and for the inspection practice
Ultrasonic-couplants and Test-Blocks
Fluorescent Magnetic-Particle consumables
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Motivation

- Clarification and explanation of the technological and technical difference of conventional UV-Sources & UV-LED-based sources
- Showing the technical possibilities and advantages of UV-LED-sources
- Explaining that optimized UV-LED-systems can extremely enhance the fluorescent inspection as well as the Quality of Inspection
- Establishing the awareness of the user, that the visibility of the indication for the human vision is the primary and unchangeable Focus in the System
- Choosing suitable UV-LED-Systems is not as simple as selecting conventional UV-source
- Introducing upcoming new parameters, background and meaning
- Upcoming standardization
Table of Contents

I. Basics of the Fluorescent Inspection Process
II. The unwritten standard: 100W Mercury-vapour bulb based UV-Sources
III. Technology shift: electric device vs. electronic system
IV. Peculiarities of UV-LED-Systems
V. New possibilities in inspection practice
VI. How to select adequate UV-LED-Source for specific application
VII. Worldwide Standardization 2014
VIII. Conclusion
I. Basics of the Fluorescent Inspection Process

a. Basics of fluorescent MPI and FPI

b. Why is a soft radiation drop so important?

c. Central importance of the UV-Source and its Reliability
I. a. The Basics of Fluorescent MPI and FPI?

- Process just helps to detect indications (see it easier)
- Process has to be:
  - reliable
  - secure
  - fast and
  - efficient and economic
- The human vision and its physiology is the UNCHANGEABLE
- Contrast between indication and background on the inspection surface is most important issue in the process!!!
- Optimal visibility of the indications by the human vision based on:

  Perfect, ergonomic viewing conditions and optimal protection
I. b. Why is a soft radiation drop so important?

Peripheral Vision (unsharp and fast):

RESPONSIBLE FOR FAST & RELIABLE
DETECTION OF INDICATIONS
ALLOWS ORIENTATION ON THE PARTS

- Realises very fast the **contrast** of the indications
- Very effective under dark conditions (mesopic & scotopic vision)
- Up to 35 times faster than foveal (central) vision
- Prime reason why well trained and experienced inspectors ‘smell’ the cracks
- Enables unconscious process who let the inspector recognize the target very fast and reliable, just when looking (moving the eyes) over the inspection area
- Navigates instinctively (central vision) to the indication
I. b. Why is a soft radiation drop so important?

Foveal (central) Vision (very sharp and slow):

RESPONSIBLE FOR INTERPRETATION OF INDICATIONS

- Catches the indication instinctively, based on the perception of the peripheral vision
- Slow vision
- Let the inspector sharply see the indication
- Generates the information (picture) that allows the interpretation
I. b. Why is a soft radiation drop so important?

- Allows the use of the main cause of fluorescent inspection: fast and secure DETECTION of indications
- Prevent tunnelview
- Enable free eye movement
- Enable tireless inspection
- Enable intuitive and natural following of the handlamp to the user’s visual focus
- Do not constrain the human vision to an unnatural staying within a beam and do not force to follow it
I. c. Central importance of the UV-Source and its Reliability

Generating fluorescent indications
(absorption of the radiation, energy transformation and emission of visible light by the fluorophores)

is totally different to visible illumination
(partly absorptions and partly reflection of the illumination)

- A failure (e.g. lost of intensity) can not be seen and realized by inspector due to the invisibility of the radiation

- If a physical existing indication does NOT appear or is not seen, due to a failure of the source or insufficient radiation area, the inspector TRUSTS that there IS NO indication

⇒ if the sources doesn’t work always, reliable and properly the whole process does NOT work!
II. The unwritten standard: 100W Mercury-vapour bulb based UV-Sources

a. All lamps are equal (based on same bulb, filter and ballast)

b. Spectral Output

c. Irradiated area

d. Advantages of conventional (bulb based) UV-Sources

e. Disadvantages of conventional (bulb based) UV-Sources
II.a. The unwritten standard: 100W Mercury-vapour bulb based UV-Sources

All lamps are equal, whoever the supplier is, they are all built on the technical identical components:

**Identical bulb, identical filter, identical ballast**

Only insignificant variation exist

All factors of influence to the fluorescent inspection process are similar:

- Similar irradiated area and similar optical characteristics
- Similar spectral emission and spectral stability
- Similar stability of intensity

**Using lamps do not fulfill at least 100% of the performance and reliability regarding ALL factors of influence to the fluorescent inspection process of 100W Mercury discharge lamps are a risk for the probability of detection (POD) and performance of the whole process!**
II.b. Spectral Output of Mercury-Vapour-bulbs (100W)
II.c. Irradiated area 30 cm distance of different sources

- 100W Hg-Lamp
- 35W Xenon Bulb
- Non-uniform UV-LED-Lamp
- Worse UV-LED
- Standard-UV-LED
- HQ-UV-LED-Lamp
II.d. Advantages of conventional (bulb based) UV-Sources

- Simple electric device
- ‘If it runs it runs correctly’
- Robust against bad external conditions of use (heat, dust, etc.)
- No qualification required, due the equality of all lamps
- Relatively insensitive regarding external thermal variations
- Relevant factors of influence primarily determined by the bulb
- Well established and practical approved
- Large irradiated area
- Soft radiation drop
- Physically fixed wavelength and relative spectral distribution
- Low price
II.e Disadvantages of conventional UV-A-Sources

- High fire- and burn-hazard
- High sensitivity regarding magnetic fields and mechanical stress
- Mortal danger (due to high electrical risk in wet areas and inside metallic tanks and vessels)
- High white-light output possible
- Bad testing conditions in particular for penetrant testing (heat, warm wind and infrared-radiation)
- Bad working conditions (hot housings, heavy-weight, etc.)
- High H&S risks: Very dangerous UV-B and UV-C -output possible

- Harmful to the environment (high Mercury- and lead-Content, low efficiency)
- Non-uniform irradiation
- Bad viewing conditions (high-visbile Output: bluish, violet or red reflections)
- Low life-time
- No instant ON/OFF
- Inflexible for specific designs
- High reflecting output in the near UV, Red and Infrared range
III. Technology shift:

from a simple electric device to a complex sophisticated electronic system

a. Conventional UV-Sources: simple wired electric devices

b. UV-LED-Systems : complex electronic systems
a. Conventional UV-Sources: simple wired electric devices

- Very small amount of simple relevant parts
- simple circuits
- Rude technical implementation
- Manufacturing is only an extreme simple mounting and connection of the very simple robust parts
- Assembling can not significant affect the system performance
- Behaviour of the main factor of influence, the power supply, is well managed by the electricity supplier
- Nearly no variations in the technical relevant product design possible
- Easy to qualify by well know and common electric checks
- Insensitive regarding external conditions
- Unchangeable, physical determined characteristics
b. UV-LED-Systems : complex electronic systems

- Huge amount of high sophisticated and very sensitive electronic components and semiconductors
- High vertical integration into many different relevant manufacturing processes
- Numberless variation and designs possible
- Much more factors of influence to the system performance like:
  - High amount of significant influencing parts and manufacturing steps
  - High variation of main components in their own manufacturing process
  - Difficult, fine and sophisticated implementation and circuitry
  - Complex, challenging and delicate assembling of many sensitive parts
  - Behaviour of entire UV-LED-system depending on many totally different, sometimes ‘small’ factors of influences
  - One single suboptimal soldering point can cause significant impact to reliability and performance of the whole UV-LED-System
- Very sensitive regarding heat and external influences
- ➔ Far ranging, for electronics common examinations necessary
  Special, new developed qualification and test methods necessary
IV. Peculiarities of UV-LED-Systems

a. Why is an extremely enlarged qualification mandatory
b. Factors of influence to the system performance
c. Disadvantage using UV-LED-Systems
d. Risks when using inadequate UV-LED-Systems
e. Advantages using UV-LED-Systems
f. (mostly) new parameters to describe UV-LED-Systems
g. How to describe UV-LED-Systems comprehensive
h. minimum Requirements for UV-LED-Lamps in NDT for sufficient process security and reliable inspection
IV.a. Why is an extremely enlarged qualification mandatory

- UV-LED-Systems are very complex and challenging electronic systems
- Correct specification in very narrow confines compared to the specification of the semiconductors and other applications
- The qualification and parameterization by the UV-emitting semiconductors if by far not adequate and can not reflect the performance of the used system
- Totally different compared to conventional bulb-based UV-Sources
- Fluorescent inspection is the most sensitive and ambitious usage for UV-LED-semiconductors, compared to other usages
- Requires a maximum reliability
- common LED-Lamp-design will cause failures
IV.b. Factors of influence to the system performance

- Thermal design, heat management and cooling concept
- Optical design
- Filters used
- LED-semiconductors
- Kind of electrical drive
- Circuit design
- PCB design
- Electronic controlling and monitoring
- Used electronic components
- Mechanical and electric design
- Ambient conditions
- Operating conditions
- Variations in the manufacturing process
- Exchange of a single component or semiconductor
- Quality insurance and qualification of the sources during and after the manufacturing process
IV.c. Disadvantages using UV-LED-Systems

- Extensive qualification needed
- More process control
- Simple repair not possible
- More work to select the right lamp
- Reduced exchangeability when using specific sources for specific applications
- Higher initial outlay
IV.d Risks of using inadequate UV-LED-Systems

- Loss of probability of detection (POD)
- Non-conformity of the inspection process
- Loss of process performance
- Higher costs of the inspection process, caused by increased need of man-power
- Incomplete examination of the inspection area
- Destruction of the fluorescent pigments and dyes
- Unnoticed lost of up to 70% of intensity during usage
- Low durability of the source
IV.e.1 General Advantages of LED-Technology

- Lower power consumption
- Long life-time
- High resistance against mechanical impacts and vibrations
- Compact devices, flexible design possible
- Low voltage systems possible
- High efficiency
IV.e.2 Technical Advantages of LED-based UV-sources in NDT

- Manageable UV-intensity
- Controllable stability of intensity
- More secure, simple, fast and trusty examination
- Perfect irradiation in all applications possible (Regarding the size, distribution and intensity in the inspection area)
- Higher reliability and quality of the testing-process
- High reliability of the source
- Ergonomic working and viewing conditions
- Maximum safety at work
- Environment friendly (free of Hg and Pb, when RohS-conform)
IV.e.3 Practical Advantages of the Usage of High-Quality UV-LED-Systems in NDT

- Perfect viewing conditions for the human vision possible
- Trusty, simple and fast inspection
- Less tiring inspection
- No high-frequency variation or perceptible flickering
- Maximum contrast
- No reflections (unhindered clear view onto testing surface [no bluish, violet, visible or infrared-output possible])
- No hot air and surface-heating output
- Uniform irradiation over larger areas
- Real instant ON/OFF
- Light-weight sources
- Combination with high-quality white-light possible
IV.e.4 Maximum Safety at Work

- UV-A-output ONLY if needed for examination, UV-A-radiation is directed to the examination area (minimal diffusion of radiation into non-relevant areas)
- Extra constant UV-A-radiation at the needed level (manageable intensity)
- No mortal danger in wet areas, boilers and vessels when using low-voltage- or battery-operated lamps
- Minimization of the UV-contamination of the user due to the constant low UV-Intensity level
- No burn hazard at fan and water-cooled-systems
- Minimal fire hazard
- Lower risk of injury
- No dangerous UV-B, UV-C or infrared-Output possible
- Free of mercury and lead (when RohS-conform)
IV.e.5 Commercial Advantages using High-Quality UV-LED-Sources

- Higher quality of testing
- Secure, efficient and fast inspection
- Faster and more reliable testing process
- Conservation of the inspectors testing-capability
- High motivated inspectors
- Lower maintenance and operating expenses
- Maximum safety at work
- Lower risk of injuries
- Maximum protection of the environment
- Maximum investment protection
IV.f (mostly) new parameters to describe UV-LED-Systems

- Peak Wavelength
- Excitation irradiance (Intensity)
- Spectral emission distribution
- Full-Width-Half-Maximum (FWHM)
- Bandwidth @10% of Maximum
- Wavelength-stability
- Stability of Intensity (during usage)
- Degradation of Intensity (longtime performance)
- Estimated life-time T70 / T50
- ‘parasitic’ visible output
- Beam Pattern & Uniformity
- Minimum Working Distance
- Maximum Working Distance
- Grade and size of soft radiation drop area (100 to 1.000 µW/cm²)
- Behaviour of UV-LED-Systems
- Ripple of LED-Current
- Recommended usage
- Typical application for UV-LED-Systems
- Typical operation time
IV.g How to describe UV-LED-Systems comprehensive

- Uniformity of the distribution of the emission
- Minimum Working Distance (distance without visible irregularities)
- Soft radiation drop at the borders of the irradiated area
- Size of irradiated area
- Spectral output (Peak, FWHM, symmetry, VIS of the wavelength-curve)
- Visible output (background light, spectrometric measured) > 380 - 800 nm
- Stability of UV-intensity, degradation and life-time of the whole system
- Wavelength-stability during operation
- Quality and stability of the supplied power and the LED-electronics
- Ripple of LED-emissions
- Allowed ambient conditions for secure and reliable usage
- Further functionalities (dimmable or switchable visible light, adaption-time-signalisation, electronic system monitoring, temperature control)
- Number of LEDs
- Recommended maintenance and overhaul cycle
IV.h minimum Requirements for UV-LED-Lamps in NDT for sufficient process security and reliable inspection

Acceptable spectral output for HQ-UV-A-LED-Sources

Peak-Wavelength: $365 \pm 5$ nm; FWHM: $< \pm 10$ nm; acceptable symmetry
IV.h  minimum Requirements for UV-LED-Lamps in NDT for sufficient process security and reliable inspection

- Peak Wavelength: 365 ±5nm
- Wavelength stability: 365 ±5nm over the whole allowed ambient temperature range
- Limited bandwidth of spectral output @50% < ±10nm; @10% of maximum <15nm
- Stability of intensity > 80 %
- Soft radiation drop at the edges (less than 50% every 2.5 cm)
- Main irradiated area should be large enough (best is larger than the part)
- Minimum working distances of the source has to be shorter than it is in practice
- NO disturbing visible (bluish) output
IV.h minimum Requirements for UV-LED-Lamps in NDT for sufficient process security and reliable inspection

- NO puls firing of the UV-LEDs
- Ripple of LED-current less than 3%
- Automatic switch-off when LED current drops or critical overtemperature occurs (e.g. battery can not supply enough energy, failure of cooling)
- Allowed ambient conditions have to be wider than they are in practice
- Clear definition of cooling system and how to check and monitor it
- NO variation of UV-intensity by the user, by control elements or variable focus
- NO visible green and/or yellow signals
- NO fluorescent part on the UV-LED-System
- Analysis and documentation of the real emission and performance of each individual source when heating-up at ambient
IV.h Minimum Requirements for UV-LED-Lamps in NDT for sufficient process security and reliable inspection

Inacceptable Spectral output for NDT-usage

- Wrong Peak
- Too broad spectrum
- Too unsymmetrical
V. New possibilities in inspection practice

- Combination UV with visible light:
  - In addition of UV
  - Instead of UV
  - Adjustable brightness of VIS
  - Automatic intuitive dimming to prevent arc eyes and flash effects during inspection

- Automatic Adaption Time Signalisation for maximum process security

- Unproblematic and safe usage in wet areas

- Electronic monitoring of cooling, temperature, LED-failure
V. New possibilities in inspection practice

- Automatic Switch ON and OFF when UV is not needed:
  - by external controllers (e.g. SPS, SPC, PLC, movement- or presence detectors)
  - by integrated controllers
- Temperature-controlled cooling system
- Full integrable in industrial process measurement and control systems for controlling and monitoring
- Flexible lamps size
- Adjustable UV-intensity ex works
- External control by foot-switches, -regulator and other controls
VI. How to select adequate UV-LED-Source for specific application

- Clarification of the needs and application
  - Part-size, part handling
  - Accessibility of the inspection area
- Clarification of needed intensity and distance between lamp and part
- Clarification of needed ambient temperature range of the source. It has to be wider than it can be in practice (45°C in a non-air-conditioned space happens in Europe)
- Clarification of Runtime (e.g. an electronic monitoring is reasonable for 24/7 usage and unneeded for 20 minutes daily use)
- Define your requirements and your main focus
- Select interesting lamp-models by technical data available
- Check Stability of UV-Intensity without moving the UV-sensor
VI. How to select adequate UV-LED-Source for specific application

- Perform practical comparisons of different lamps under real conditions, don’t buy from datasheet
- Put a white sheet of paper under the running lamp at minimum working distance and move the lamp when checking homogeneity
- Check quality of visible light, if available (uniformity, glare, colour rendering)
- Ensure that user is not able to vary UV-intensity
- NO green/yellow signals within the vision area
- No fluorescent parts an the UV-LED-system
- Sufficient stability of intensity over the whole temperature range
- Qualification report of the measurements of each individual lamp is required to enable the possibility of requalification and ensure sustainability according to pending standards
VII. Worldwide Standardization 2014

- Rolls-Royce, who forbid the usage of UV-LEDs in the past, has developed a standard that shall be published until the end of the 2014, ADS SIG NDT shall follow Aerospace industry-wide.
- ASTM is working on a new standard especially for the qualification of UV-LED-sources for NDT since 2012, next ballot 2014/2015.
- NADCAP NDT task-group formed an Ad-hoc-Team to specify a technical baseline and work-out a standard questionnaire.
- DIN EN ISO standardization just started an new working item regarding UV-LED-sources (timeframe: 2 to 5 years).
VIII. Conclusion

- LED-based UV-Sources are not simple electric lamps, they are electronic device that require adequate qualification and maintenances.
- Well qualified and designed high-quality UV-A-LED-sources can easily and completely substitute conventional bulb-based-UV-lamps without any technical and practical disadvantage in NDT
- Fluorescent inspection processes can be improved using optimal UV-Sources
- New Standards have to replace the ‘unwritten’ Standard by using the very similar bulbs, filters and ballasts
- Selecting and buying adequate UV-LED-lamps is much more complicated and complex due to high variability, further it is necessary to
- When using LED-based sources in practice we have to respect and check (manually or electronically) more relevant parameters,
- Higher qualification and control work to do when not electronically monitored (e.g. correct operation of all LED-elements and cooling system)
- Many new and great applications can be realized (e.g. combination with dimmable white light)
Thank you very much for your attention!

Any questions?